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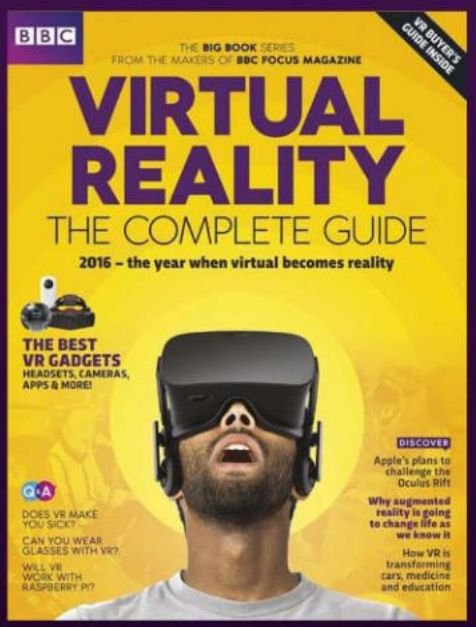

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WELCOME

Has anything changed our lives more than the internal combustion engine? Just think, for the vast majority of human history, we could travel only as fast as our horses carried us. But in little more than a century after the first proper engines came along, our maximum ground speed would break the sound barrier. Along the way, we turned the car from a privilege for the wealthy few into something most people can own. And yet, if you were to write a history of cars in a few hundred years from now, those powered purely by fossil fuels will seem as antiquated as steam trains seems today.

The car industry has always moved fast. But this could be the most promising era for transport since we stepped into the very first motor carriages. Because we're now in the time when some of our once far-fetched ideas finally reach the road. Driverless tech is already with us (p16). Electric cars have entered the mainstream (or maybe that should be re-entered, as you'll see on p66). And your options list is about to get a whole lot more exciting – forget leather seats and Bluetooth, you'll soon be wanting augmented reality windscreens (p42) and virtual butlers (p40).

There's still more to do. Self-driving cars are fine, but soon they'll need to make life-and-death decisions like a real person (p20). Then there's the roads on which they drive, which also need to smarten up (p76). Or perhaps we need to abandon roads altogether, for life in the skies (p110). Whatever happens, the next chapter in the story of the car will look very different to the last. Enjoy the ride.

Dan Read, Editor

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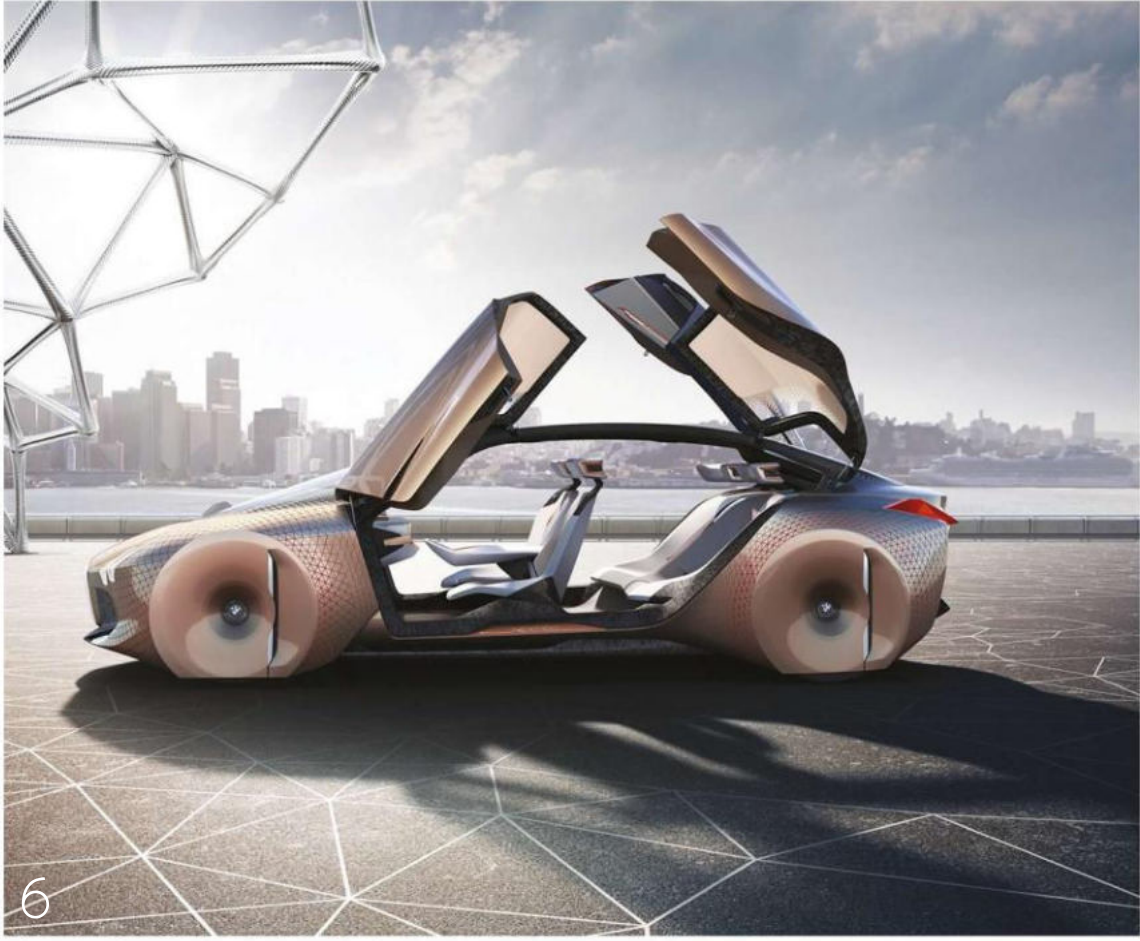

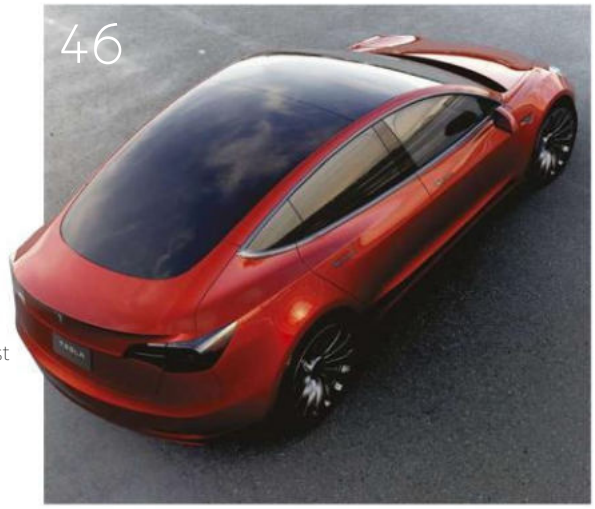

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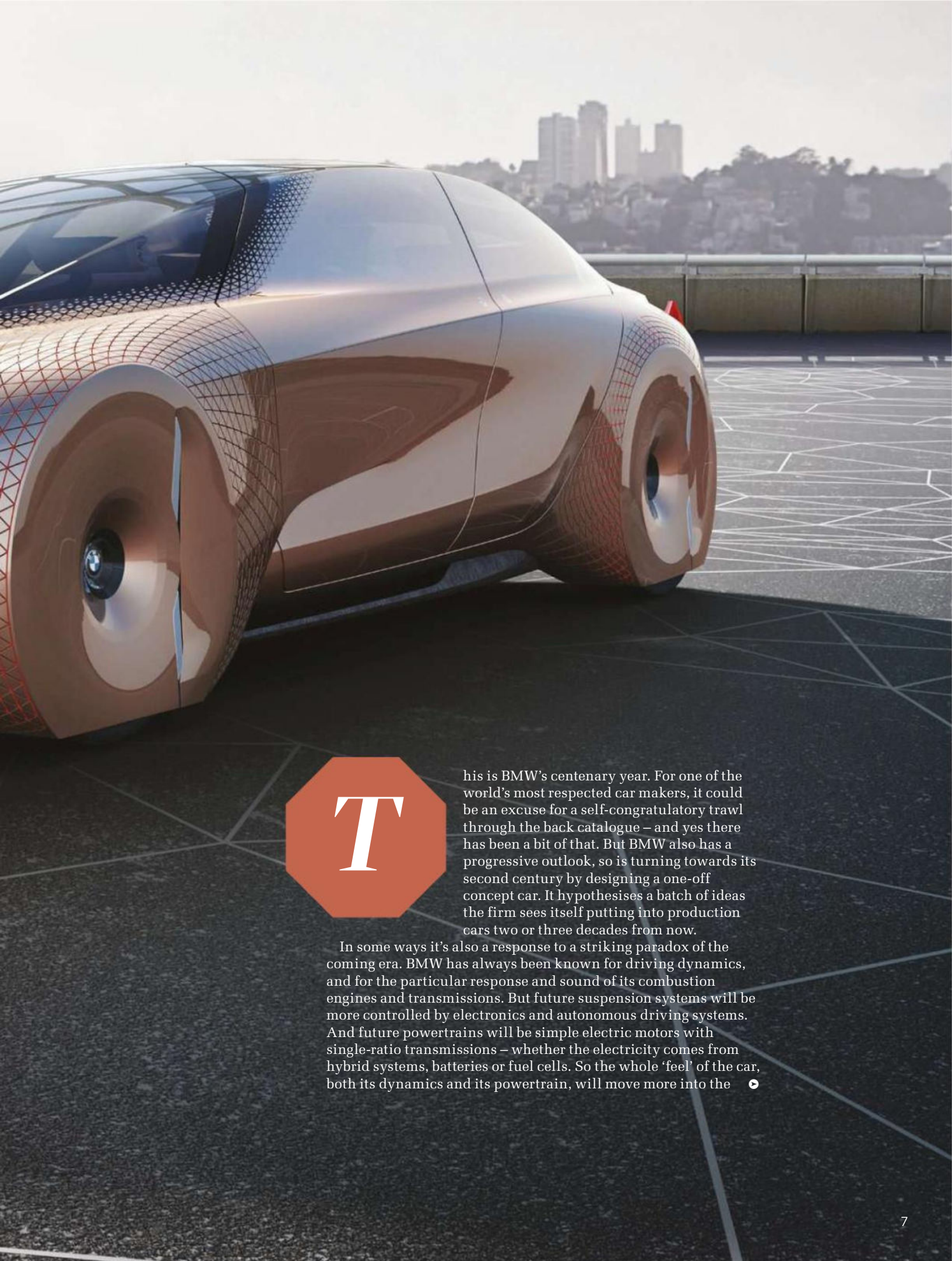
PHOTOS: BMW, APPLIED MINDS/BRAN FERREN , TERRAFUGIA, AT&T ARCHIVES & HISTORY CENTER, TESLA, ROBORACE

WARP SPEED

BMW's bold vision of the future is a shape-shifting, self-driving supercomputer with X-ray vision – a supercar with superpowers

Words: **Paul Horrell**



This is BMW's centenary year. For one of the world's most respected car makers, it could be an excuse for a self-congratulatory trawl through the back catalogue – and yes there has been a bit of that. But BMW also has a progressive outlook, so is turning towards its second century by designing a one-off concept car. It hypothesises a batch of ideas the firm sees itself putting into production cars two or three decades from now.

In some ways it's also a response to a striking paradox of the coming era. BMW has always been known for driving dynamics, and for the particular response and sound of its combustion engines and transmissions. But future suspension systems will be more controlled by electronics and autonomous driving systems. And future powertrains will be simple electric motors with single-ratio transmissions – whether the electricity comes from hybrid systems, batteries or fuel cells. So the whole 'feel' of the car, both its dynamics and its powertrain, will move more into the

"There are two main driving modes. The first, called 'Boost', is where the driver is in charge. The second, known as 'Ease', lets the machine take over"

domain of software. There's a danger they might be easily reproduced by rivals. So BMW is working hard on new expressions of premium and dynamic design for the connected, digital, sharing era.

The Vision Next 100, as it's rather un-snappily named, is supposed to be a car you would want to drive. It includes some novel driver-assist features aimed at making you a better driver rather than simply wresting control from you. But when you want it to, it can drive itself, and in that state it morphs its interior into something altogether more comfortable and sociable. And ironically for a company whose name translates as the Bavarian

PHOTO: BMW

Engine Factory, BMW is revealing nothing about the car's proposed form of propulsion, other than to say it's zero emissions.

ABOVE: **Look, no hands! The Next 100's steering wheel retracts when the car's driving itself, so you can sit back and Tweet**

ASSISTED AND AUTONOMOUS DRIVING

The BMW has two main driving modes. The first, called 'Boost', is where the driver is in charge. The second, known as 'Ease', lets the machine take over. The design of the whole interior very much follows on from these states.

In Boost mode, the driver faces straight ahead, with the steering wheel and centre console in the positions we'd find familiar today. Conventional instruments are nowhere to be seen. Instead, the entire windscreen functions as a head-up display. It doesn't just project familiar information such as speed and navigation instructions, either. It adds augmented reality, for instance superimposing into the field of view a line for the driver to follow for smoothest cornering, and the ideal braking point – in effect driver coaching.

It also projects, in a representation of their real position, hazards which the car's external sensors and cameras can see but which are still obscured from the driver's field of vision. That ability will be enhanced by the car's extensive external ➤

“BMW already sells cars that can follow the car in front, even braking, accelerating and steering by themselves”

networking. For instance if the car in front, around a blind bend, skids on a patch of ice, it will broadcast the position of the ice back to your BMW. At city junctions, the same system would warn of other cars before they came into view, or point to a cyclist hidden behind a truck. It could also simulate the view ahead when reality is blanketed in fog, and assist with night vision.

So Boost would make you a better and safer driver. But if you don’t want to drive at all, switch to Ease mode. The steering wheel retracts into the dashboard, the centre console glides backward and the front seats change shape and position, turning into a more conversational, lounge-like V-shape formation. The car becomes fully autonomous. Because the driver needs far less information, the head-up display takes on a new role, as a connected entertainment and media centre.

How real or feasible is all this with today’s tech? Surprisingly close. Already, BMW sells cars that can – on a slow-moving urban road – follow the car in front, braking and accelerating and steering by themselves. They can do the same on motorways at high speed. Tesla’s Autopilot feature allows autonomous driving in a wider range of situations, but still can’t negotiate junctions or city streets. Mercedes has demonstrated that – using little more hardware than the sensors already fitted to its S-class – a car can drive through cities and rural roads. But to do so reliably its navigation system needs higher-resolution, fully updated data. That next-gen mapping is underway now. Google’s autonomous driving fleet, extensively tested in

The seats swivel slightly to face each other, so you can look your terrified passenger in the eyes...

Hazards, such as wobbly cyclists, are pointed out to the driver on a fully connected smart screen

PHOTOS: BMW

Who knows, If it flaps its wings fast enough, it might even take off....

several US states, points to the same thing. So most experts believe that autonomous driving will be technically feasible in a very few years from now. Sure, hurdles exist in the areas of traffic law and insurance (who's responsible if an autonomously driven car does crash?) but they're being tackled.

Some of the features of BMW's concept – namely the warnings of hazards around the corner or hidden across a junction – rely on a level of external communication that's as yet unavailable. Protocols are being developed across the industry so that cars will be able to distribute position and hazard data in spontaneous peer-to-peer networks. But standards adoption is very slow. Over the years, what has happened instead is that cars' ability to sense their surroundings has improved so fast that they haven't needed as much externally supplied data as was expected. For example, many traffic engineers once proposed that every speed limit sign carry a transponder to tell passing cars the limit. Nowadays many quite mundane cars simply use cameras to read the signs themselves.

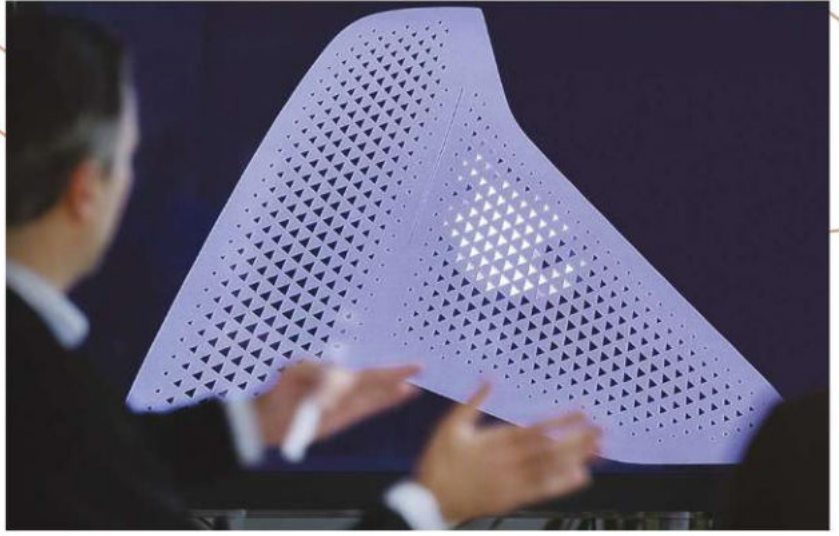
TRULY SHAPE-SHIFTING

One of BMW's classic body design themes is to put the wheels well towards the ends of the car. It gives what designers call a 'strong stance' – the car seems to be hugging the road. But the Vision Next 100's bodywork is pulled down to cover the wheels, to reduce air turbulence and drag. Which is all very well in a straight line, but what happens when the front wheels need to steer? Step forward another innovation, called 'Alive Geometry'.

ADRIAN VAN HOOYDONK

Senior Vice President, BMW Group Design

"If you can imagine the future, you've made the first step," says Adrian van Hooydonk. To run the design department of a car company these days isn't just about drawing future-friendly wrappers for the vehicles. Van Hooydonk acts as a seer across the whole gamut of experiences through which a future customer might touch his company. He thinks about the way new forms of mobility will change our relationships with cars, and new forms of ownership – or non-ownership in the case of car sharing. He's re-imagining the ways connectivity will transform our journeys, and corralling that transformation into new interfaces. He's figuring out how we'll use our time in cars when we no longer need to drive, but also ensuring that at times we'll still want to take control. And amidst all the change, van Hooydonk has to imbue the whole thing with an essence of his brand – to make sure his customers still feel instinctively that they're touching BMW rather than any rival.



Some 800 moving triangles are set into the car's surfaces, mainly on the front wings and the instrument panel. By opening and closing, they enable the skin to change shape and contour. So it can stretch over the front wheels as they turn.

Inside the car, the same material covers the dashboard. As the triangles open, they reveal a lower layer coloured red. This is what BMW calls a 'preconscious signalling device' in the occupants' peripheral vision. In Ease mode, the triangles subtly prepare the passengers if the car is about to brake or turn, moving in a Mexican wave across the dashboard. Passengers would brace themselves almost without thinking. Sounds like a worthwhile remedy for car sickness. In Boost mode, if a danger is coming up, a wave of red spreads across like a gesture towards the hazard.

BMW admits that something like Alive Geometry is still a long way from reality. To be produced, it would probably need what engineers call '4D printing'. In 3D printing the shape of an object is

printed up to match a digital model, in a uniform material. For the fourth dimension, the printed piece would be made from multiple materials, giving scope for active, even intelligent, parts.

The car has very few physical controls. Instead, cameras read the position of your hand and fingers, so you can control the car's features and menus by gestures – pinching and swiping in mid-air. Gesture control is already available on BMW's 7-series saloon, although it has a limited vocabulary so far.

GETTING TO KNOW YOU

The Vision Next 100 is networked into BMW's servers, which are expected to know more and more about the driver's life. Data includes your travelling habits, your diary and address book, the way you configure your car, your kind of music – even the embarrassing tracks – and so on. Thus aware, it can for instance pre-program destinations according to the time of day, automatically go to recharging points, find entertainment for your likely mood, and so on. Whether you view this as helpful or creepy, it's no more than an extension of the virtual assistants that are already finding their way into most of our lives.

BODYWORK AND MATERIALS

The basic body structure isn't envisaged as steel, because that's too heavy and, of course, would have a damaging impact on energy consumption and range on a charge. Instead much would be carbon fibre, a material BMW is already using in substantial parts of some of its road cars. Inside, there's an emphasis on sustainable cloth rather then leather – BMW thinks many future buyers will be vegetarians. As a bonus, cleverly textured mono-materials will also ease recycling.

The car is 4.9m long, the same as today's 5-series, but BMW says it has the interior room of its full-size 7-series. Because of the flexible skin and sleek shape, the drag coefficient is just 0.18.

What's perhaps most surprising, and a true achievement, is that despite the futuristic shape of the body, it still somehow looks like a BMW. Look, there's even a traditional BMW double grille, although there's no engine behind it – instead it's used as a porthole for all the on-board sensors.

But it's not just these styling details that say 'BMW'. Even though in recent years the firm has joined the trend for crossover SUVs, and even though the Vision Next 100 has concept-car tropes such as gullwing doors, the car's basic shape is a futuristic take on a traditional sports-saloon. Such saloons have been BMW's heartland since the 1960s. Even in an era of disruptive ideas and transformation, not everything has to change.

PHOTOS: BMW

BUY IT NOW: THE BMW i3

Early manifestations of many ideas in the Vision Next 100 are already on the road in the BMW i3. Its electric drive gives acceptably lively performance for urban or motorway driving, and a range of about 100 miles (for the basic, pure-EV version rather than the version with a range-extender combustion engine, which is able to travel further before needing recharging or refuelling). The i3's passenger cell and external body panels are mostly carbon fibre, made using lower-cost methods developed by BMW itself. The body offers saloon-car interior space in compact overall dimensions, and it's shaped for extremely low aerodynamic drag.

The lounge-like interior abandons BMW's familiar driver-focus, for a more sociable, relaxed feel. Critical to the i3's usability are its online functions. The navigation system will seek out recharging points when the battery runs low – and check online to ensure they're unoccupied. Alternatively, if your destination lies beyond your range, it'll direct you to a car park near a station or bus stop, and look up timetables to finish your journey. It transfers those instructions to your phone, so you can move seamlessly onward.

BMW i3 from £30,980; bmw.co.uk

FLASHBACK

BMW'S OTHER SHAPE-SHIFTER

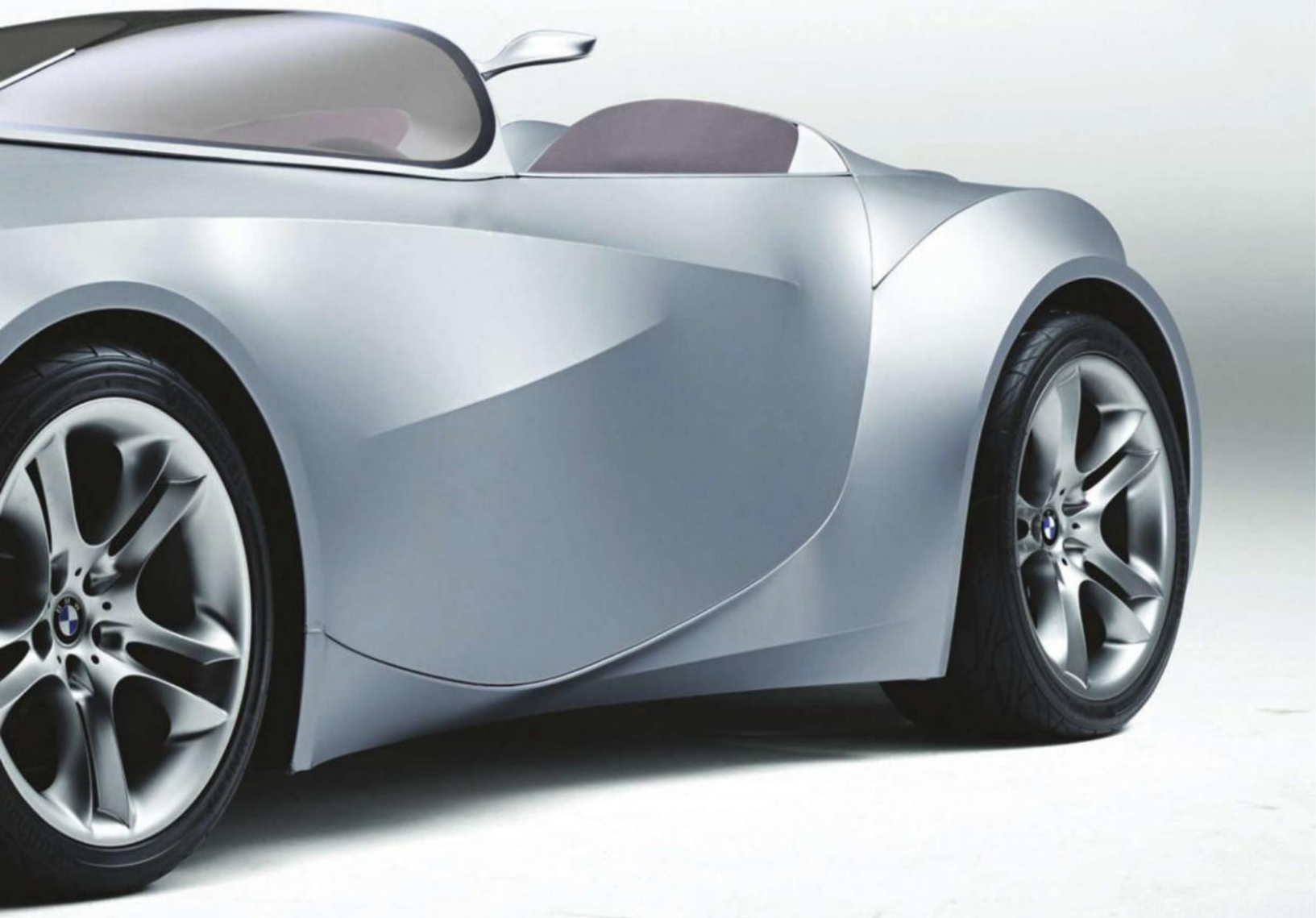
Half car, half haberdashery experiment. Meet the weird and wonderful BMW concept that didn't quite make the cut

Words: **Dan Read**

The Vision Next 100 (see previous page) isn't BMW's first concept car, not by a long shot. In fact, it's not even its first shape-shifting car. That title goes to the GINA Light Visionary Model of 2008. It too was a showcase for some strange new ideas, the most obvious being the polyurethane-coated Spandex bodywork that formed a stretchy, extremely tight-fitting skin around a metal frame. Yep, someone actually thought the Car of the Future would be shrink-wrapped in Mr Motivator's trousers.

What was the point in that? They key was that aluminium frame, which was designed to lengthen, shorten, expand and contract at the driver's command. Want a big wing for more downforce? Just press a button, let the actuators do their work, and it shall be done. Need to lose the wing for increased top speed? No problem. Fancy slimming down for a tight parking spot? You get the idea.

So the bodywork had to be stretchy in order to move with the shape-shifting chassis. The Spandex was also slightly translucent, so the taillights could shine right through it, while around the front, tiny motors pulled back the skin to reveal the headlights. Whether it would have passed any crash tests is another matter altogether, but hey, at least you could iron out the dents.



AUTONOMOUS TECH NOW & NEXT

From a helping hand to fully robotic takeovers, here's the autonomous driving tech we have already, and some that's just around the corner

Words: **Dan Read**

NOW

TESLA AUTOPILOT

After the most recent over-the-air software update, and by using its cameras, radar and ultrasonic sensors, the Model S can now steer itself along a motorway, change lanes and adjust its speed according to traffic. The tech it uses is fairly common; the difference is that it's brought together in one mode that actually allows the driver to take their hands off the wheel. It can't see beyond the car in front, but it will stop you crashing into it.

BMW 7 SERIES

Like the Model S, the new 7 Series can pretty much drive itself down the road, though the tech is presented as more of a helping hand than a full takeover. So although it can regulate its speed and keep you between the white lines, you must keep your hands on the wheel and, as with the Tesla, the system is reactive rather than proactive, meaning it won't sense that a car in the inside lane is about to pull out and overtake a lorry. That's down to you.

MERCEDES E-CLASS

Most cars with a fully autonomous vehicle licence are specially built prototypes. The Mercedes E-Class, however, is the world's first standard production vehicle to be granted a test licence for autonomous driving. Taking the Tesla and BMW tech one step further, the E-Class isn't necessarily dependent on road markings; it can adjust its speed according to speed limits logged in its satnav, and will help you swerve around errant pedestrians.

AUDI RS7 PILOTED DRIVING CONCEPT

Last year, Audi's autonomous, 552bhp RS7 lapped a race track faster than a driver could manage in a non-robotic version of the same car. Firstly it's 'shown' the track by a human being, then it finds the fastest way around using a combination of stereo cameras and GPS data.

LANE ASSIST

Almost every carmaker offers this somewhere in its range, and these days you'll find it even on the most affordable cars. All the systems are broadly similar, and use a camera to read road markings. Passive systems simply warn if you're drifting out of a lane, usually with a bong or a vibrating steering wheel (examples include the Mazda CX-3); active systems actually steer the car back onto the straight and narrow for you (as seen on the VW Golf, among others). Both know if you're doing it intentionally, either because you've made a deliberate steering input or if you've used the indicator.

ADAPTIVE CRUISE CONTROL (ACC)

Like regular cruise control, but with the addition of a radar to maintain a set gap between you and the car in front. It went mainstream with the 1999 Mercedes S-Class, and today forms the basis for other semi-autonomous features such as emergency braking systems. And the tech isn't reserved for expensive cars, as proven by the Skoda Octavia.

SELF-PARKING CARS

Again, this has been around for a few years, and removes the bother of parallel parking by doing it for you. Different systems have different ways of sensing objects around the car (sensors, radar, cameras or all three), but all work in broadly the same way: the car detects other parked cars, the size of the parking spot and the distance to the kerb, then steers into the space – you control speed with the clutch and bake pedals, but it does the steering. If it's not fitted as standard it'll cost around £500, and you'll find it on cars such as the Ford Focus, Seat Alhambra, BMW i3, and Skoda Superb.

VOLVO PILOT ASSIST II

Volvo's latest driver assistance programme, available on the new XC90 and upcoming v90 and S90, is similar to Tesla's Autopilot, though it bongs like the BMW (left) if you go hands-off for more than 10 seconds.

MERCEDES FUTURE TRUCK 2025

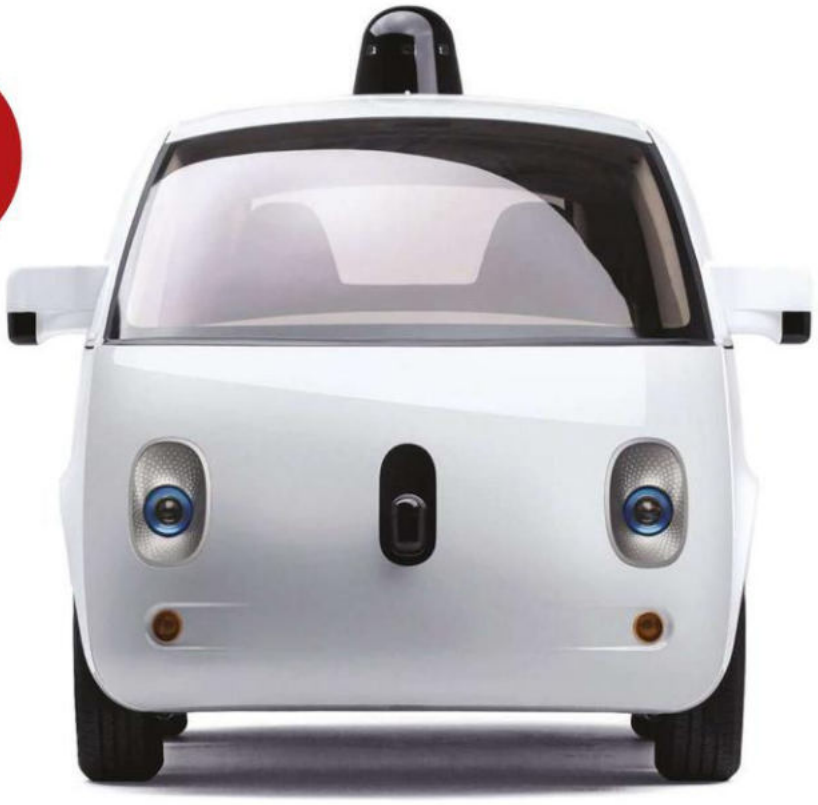
Merc's self-driving lorry is already at the prototype stage. And when you think about it, autonomous trucks make even more sense than driverless cars – they won't be limited by the length of time a driver can go without a break, so they could deliver much more. Think what that'd mean for the economy.

PHOTOS: GETTY, NEWSPRESS, VOLKSWAGEN AUDI GROUP

NEXT

THE GOOGLE CAR

The main difference between the semi-autonomous tech already fitted to today's cars and Google's vision of the future is that Google will do away with the steering wheel altogether. Its driverless pods, capable of steering and navigating all by themselves, rather than just helping you along, are already on the streets and highways of America – currently they're racking up about 10,000 miles a week as the company negotiates the technological, legal and moral minefields between today's prototypes and the production-ready model of the future, which the company says should be on the market as soon as 2020.

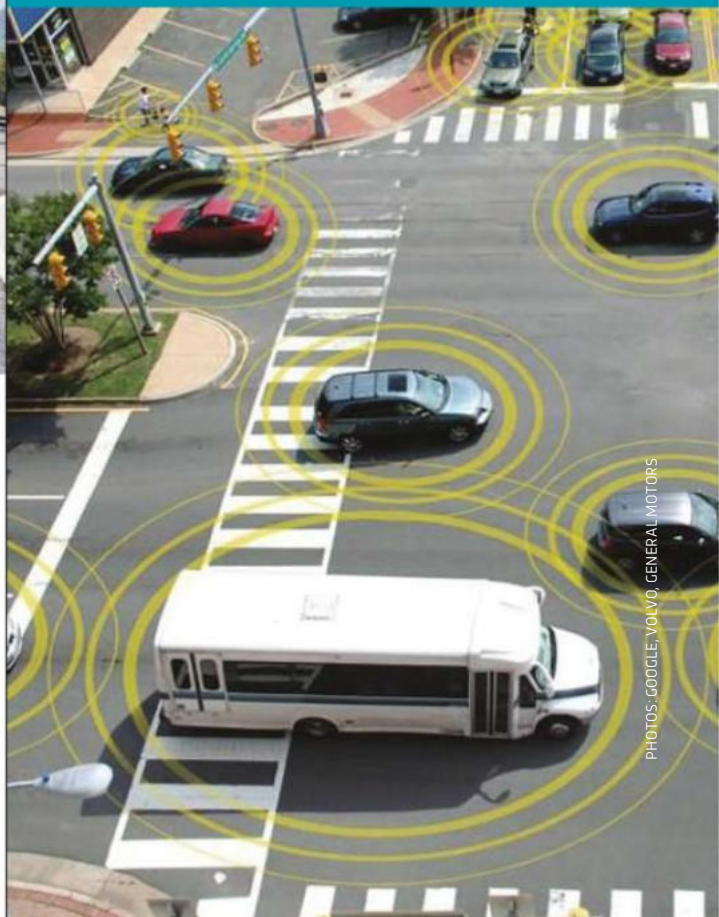


VEHICLE-TO-VEHICLE (V2V) COMMS

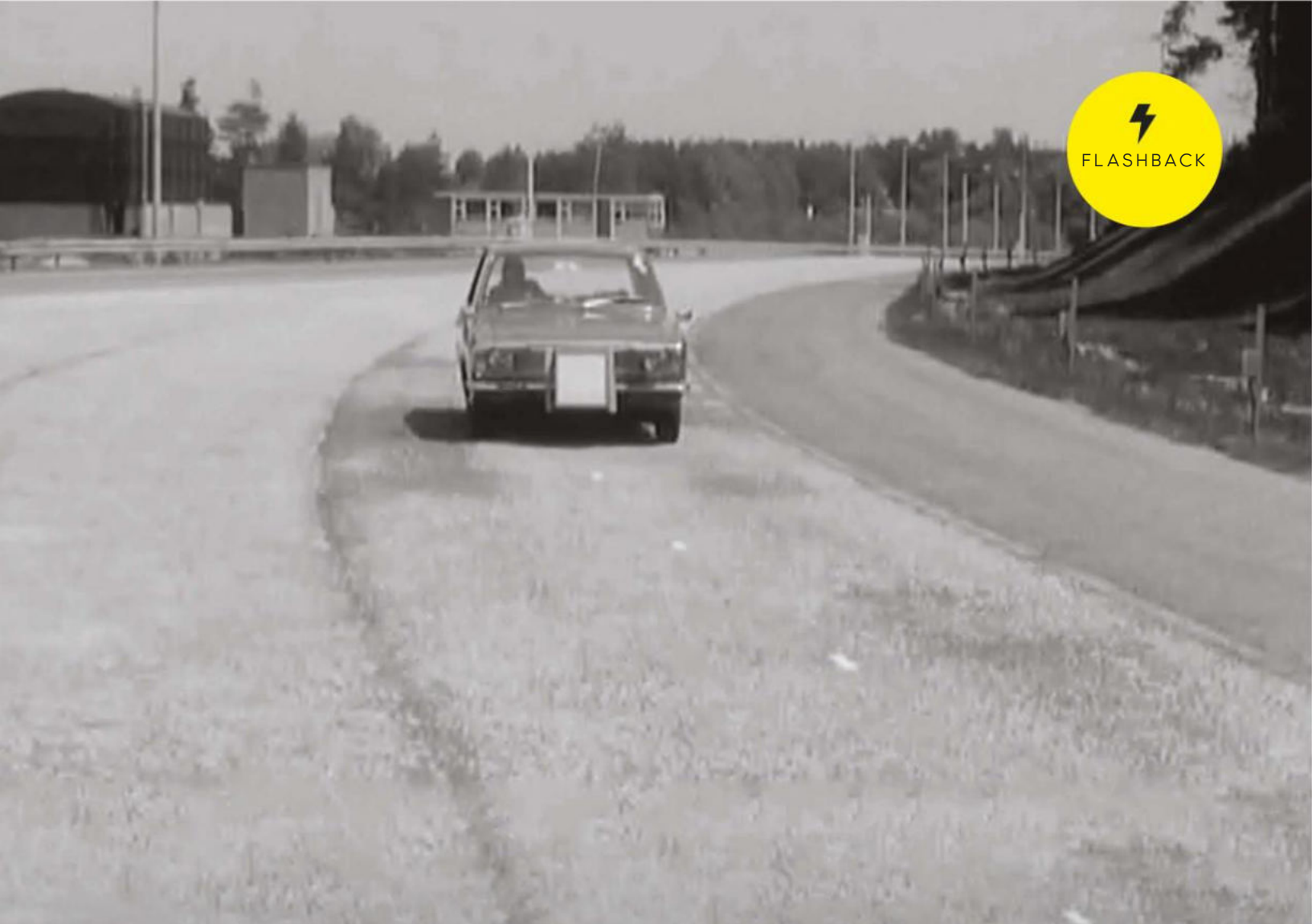
What if, on top of all the driver assistance and navigation tech, cars of the future could actually talk to each other? Not only could they alert each other to their presence, but also to other hazards such as potholes and ice patches. In 2014, the US DoT conducted a V2V experiment in which 3,000 vehicles were fitted with devices that allowed them to communicate over a WiFi-like network, with the aim of reducing collisions and smoothing traffic flow. The test was successful – it quickly expanded to 9,000 cars in Michigan, with 10,000 more planned for New York this year.

PLATOONING

If the cars of the future can drive themselves and talk to each other over wireless networks, they can potentially follow each almost nose-to-tail, forming long road trains or 'platoons'. While there are obvious issues – we're not all travelling to the same place, of course – it could work on longer stretches of motorway, where it would effectively increase network capacity, reduce congestion and improve fuel economy.



PHOTOS: GOOGLE, VOLVO, GENERAL MOTORS



FLASHBACK

THE WORLD'S FIRST ROBOCAR

If you think driverless cars are a slightly scary prospect in 2016, imagine what people must have thought of them in the 1960s

Words: **Dan Read**

There's an infamous story from the Nineties about a car journalist who – on a closed test track – set the cruise control at 70mph, left the driver's seat and clambered into the back of the car where he sat and read a newspaper. The track was a massive, banked circle, so each lane had a certain speed at which you could take your hands off the wheel and let the gradient of the road effectively steer the car.

A risky move, you might say, but the point is that ever since the car was invented, we've been dreaming of a time when it would somehow drive itself. First we weighed down the accelerator with a brick, then came cruise control, and – as early as the 60s – we began experimenting with full autonomy.

The image above shows an experiment by the British Road Research Laboratory, in which it tested one of the world's first driverless cars. It was guided by what the RRL called a 'magnetic rail' – coils in the road were sensed by a receiver on the front of the car, which in turn was plugged into the steering and throttle controls.

So it was only really autonomous when following a very specific route, and it couldn't swap lanes. So it was like a giant Scalextric set, but in the 60s, even a heavily guided robocar would have been promising news. "Researchers say that robot cars may well be in everyday use within 30 years," said a report at the time. Their timescale was a little ambitious, but they were certainly on to something.

PHOTO: AP ARCHIVE

PHOTO: GETTY

COULD YOUR DRIVERLESS CAR CHOOSE TO KILL YOU?

Two kids are in the middle of a mountain road. Your car could drive straight into them, or avoid them by swerving off the side, killing you in the process. So which choice should it make?

Words: **Heather Bradshaw-Martin**

Heather is an automotive software engineer and test driver. She holds a PhD in bioethics from the University of Bristol.

The sound of screeching tyres followed by a bus hurtling directly towards you. It's not exactly something you'd want to come across when cycling up a steep, narrow road. But in March 2015, on Franschhoek Mountain Pass in South Africa, that's just what one cyclist was faced with after a bus driver swerved in an attempt avoid two other cyclists while negotiating a sharp corner. The bus overturned and three passengers lost their lives. In the investigation that followed, the police talked of prosecuting the bus driver for 'culpable homicide', a charge resulting from the negligent killing of a person according to South African law. But what might they have said if the bus had been driven by autonomous software?

The driver was faced with a rare and complicated type of moral dilemma in which they were forced to choose between two bad options. Analysis of the above scenario raises two main questions: the first is to ask whether the accident could have been avoided by better vehicle maintenance, more careful driving, better road design or other practical measures and whether there was negligence in any of these areas. The second is to ask that if the accident was not avoidable, then what was the morally least bad action?

"Driverless cars will be able to stop extremely quickly once they detect a hazard. Also, they will never get drunk"

When thinking about these issues in terms of autonomous vehicles, the first question is relatively easy to answer. Driver software will have faster reaction times and be more cautious and physics-faithful than human drivers, meaning driverless cars will be able to stop extremely quickly once they detect a hazard. Also, they will never show off or get drunk. However, their sensors and image classification processes will remain cruder than human perception for some time to come, meaning they may not recognise or classify unexpected hazards the way humans do. They won't be able to reliably tell the difference between children and adults, for example. Nor will they know whether other vehicles are empty or are carrying passengers.

Some commentators believe that once the technology is perfected, autonomous vehicles could provide us with a completely accident-free means of transport. Yet large-scale statistical analyses, such as those carried out by Noah Goodall at the Virginia Department of Transportation, indicate that this is unlikely. Thanks to the existence of pedestrians, cyclists, and even animals, our roads are too unpredictable for any autonomous system to take everything into account.

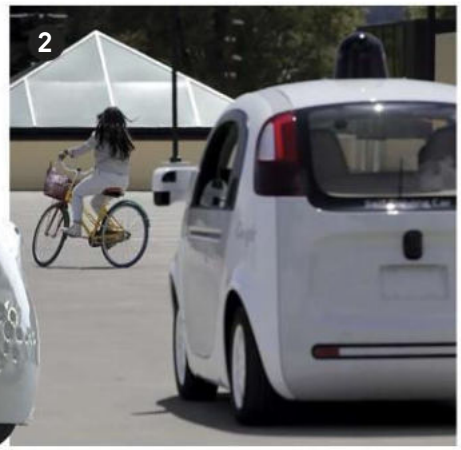
So how do driverless cars fit in with the moral question? Firstly, autonomous vehicle driver software won't have had years of real-life experience to learn the nuances of morality through praise, blame and punishment the way a human driver has. Nor will it be able to use its imagination to build on these previous learning experiences.

Imagine a similar situation to the South Africa scenario. A vehicle being driven completely by software and carrying one passenger is travelling uphill around a corner on a narrow two-lane mountain road. Two children are riding bicycles down towards it on the wrong side of the road and a heavy truck is approaching in the other lane. To avoid the children, the car can head for the truck or drive off the side of the road, but if it stops the children will hit it. Driving into the truck or off the precipice will likely kill the human passenger but save the children. Attempting to stop could lead to the children being killed if they crash into the car, yet the passenger will be protected. What should the car's software be designed to do?

RARE DILEMMA

Of course, such dilemmas are rare occurrences but they are nevertheless of key concern to engineers

1 Self-driving pods like this one are already being tested in the UK
2 Google says cyclists are safe when its driverless car is on the streets
3 In the Franschhoek accident, the bus driver swerved to avoid two cyclists – but did he have an alternative option?



PHOTOS: GETTY, PRESS ASSOCIATION

When faced with a life-or-death situation such as this, self-driving cars will be forced to make a moral decision. But would you buy an autonomous car that might deliberately sacrifice your life in order to save another?

> **"A human driver might instinctively flinch away from a large object like a truck, without being able to process the presence of cyclists"**

and regulators. But whereas the human bus driver in the South Africa incident had only a frightening fraction of a second to make a life and death decision, the engineers have hours and hours in the safety of an office to design how the vehicle's driver software will react. Of course, this means that they cannot claim that they reacted 'instinctively' due to time pressure or fear. In the event of an accident, courts will say that the engineers have programmed the software rationally and deliberately and thus expect them to be fully morally responsible for their choices. So what must they consider?

There are three broad schools of thought. One: autonomous driver software may be expected to operate to a *higher* moral standard than a human driver because of the lack of time pressures and emotional disturbances and its greater processing power. Two: it could be expected to operate to a *lower* moral standard due to the sensors' lack of classificatory subtlety and the overriding belief that only humans can act ethically because software cannot be conscious or feel pain. Three: software may be expected to operate to the *same* moral standard as applies to human drivers.

All three options imply that the moral standard expected of human drivers in such dilemmas is definitively known. But when forced to act quickly, humans will often use their instincts rather than conscious, rational analysis. Instincts may be honed through life experience or deliberate practice but they are not under conscious control at the point of application. Our emotions can also influence instinctive action. So a human driver might instinctively flinch away from a large object like the truck, without being able to process the presence of the cyclists. Or, a human with different instincts might act to protect the vulnerable children without recognising their own danger. Such unconsidered reactions are hardly moral decisions that are worthy of praise or blame. So what would moral behaviour require if we set aside the confounding factors of time and emotion?

The study of such questions takes us into the territory of ethical theory, a branch of philosophy concerned with extracting and codifying the morally preferable options from the morass of human behaviour and beliefs. Philosophers have developed logically consistent theories about what the morally preferred actions are in any given situation.

Today, two main contenders exist for the top theoretical approach: consequentialism and deontology. Consequentialist theories say the right action is that which creates the best results. Deontological theories say the correct action is that in which the people's intentions were best, whatever the results. Despite starting with different founding assumptions about what is valuable or good, these two theories agree on the morally preferable action in the majority of common situations. Nevertheless, they do sometimes differ.

MACHINE ETHICS

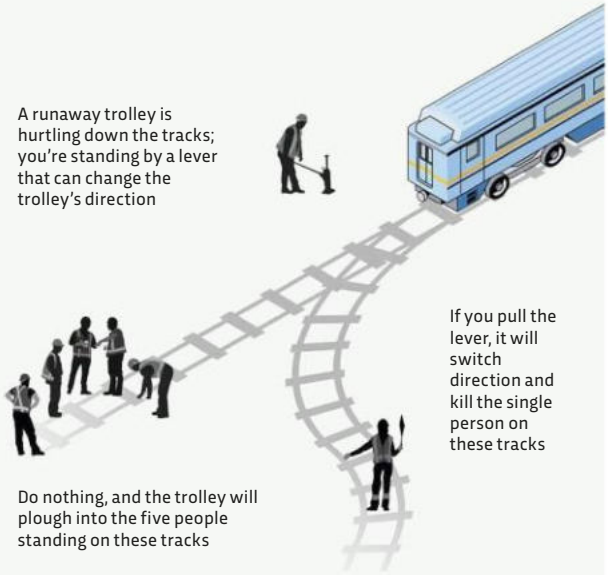
Both consequentialism and deontology are based on consistent reasoning taken from a small set of assumptions, which is something algorithms can do. So, can we write algorithms that will calculate the best course of action to take when faced with a moral dilemma? Those working in the small scientific field of machine ethics believe that we can. Artificial intelligence researchers Luis Moniz Pereira and Ari Saptawijaya have been collating, developing and applying programming languages and logic structures that capture deontological or consequentialist reasoning about particular moral problems. These programs are limited in scope, but their work suggests that it would be possible to program an entity to behave in accordance with one or other of the major ethical theories, over a small domain. This work is often criticised, not least for not covering the entire range of ethical problems. But a slightly deeper look at moral theory suggests that's inevitable.

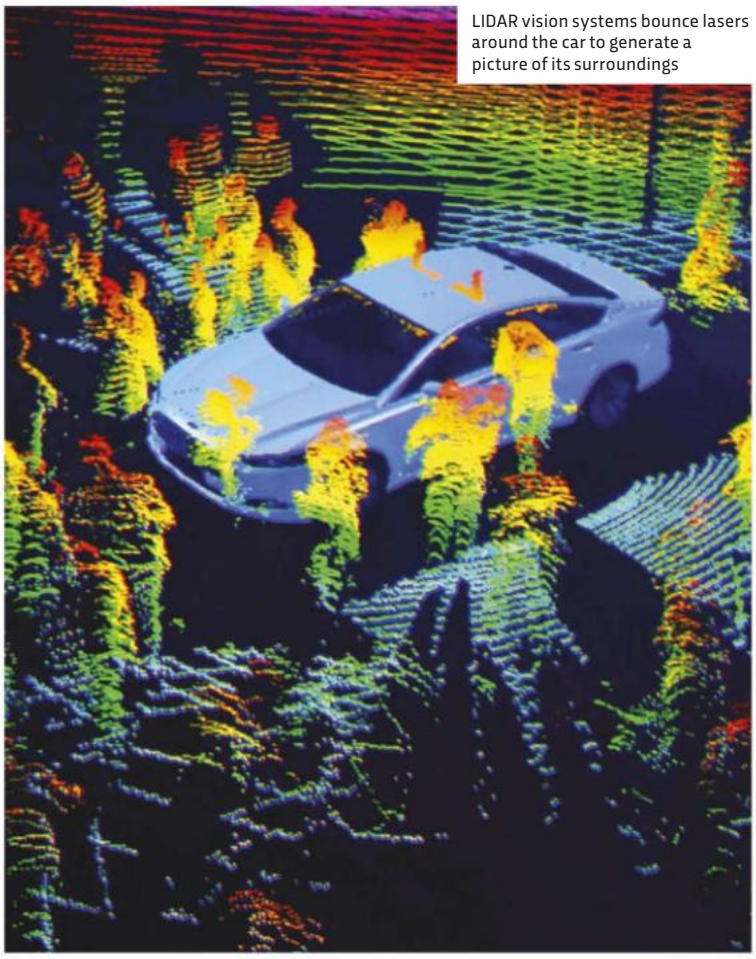
Most cases where the two moral theories agree are easy for courts of law to decide. But there are certain types of cases in which judges must call on the

PHOTOS: GETTY, ALAMY

THE TROLLEY PROBLEM

This popular ethics dilemma makes you choose between killing one person or five, and was first introduced by philosopher Philippa Foot





LIDAR vision systems bounce lasers around the car to generate a picture of its surroundings

wisdom drawn from years of courtroom experience. Examples include trials for war crimes, shipwreck and survival cases, medical law, and also road accidents. Because of their complexity and the moral discomfort they cause, cases such as these attract lots of legal and philosophical attention.

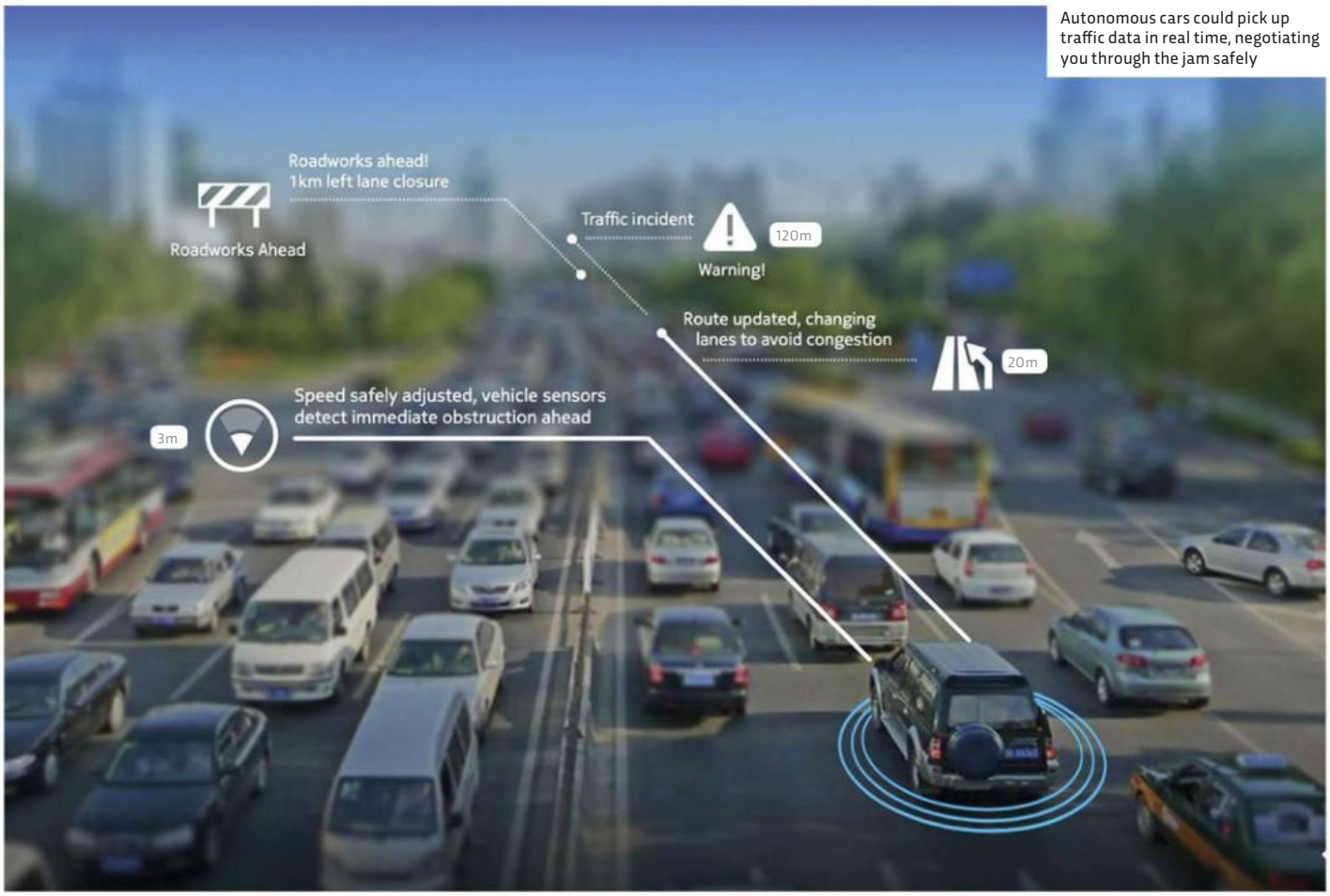
TROLLEY PROBLEM

In ethical theory, complicated moral dilemmas are named 'trolley problems' after a thought experiment that was introduced by British philosopher Philippa Foot in 1967 (see diagram above). The experiment asks you to imagine a runaway trolley (tram) travelling at breakneck speed towards a group of five people. You are standing next to a lever that can switch the trolley to a different set of tracks where there is just one person. What's the right thing to do?

The two main ethical theories disagree about the morally correct course of action in trolley problems. Humans also disagree with which is the best course of action. Studies show that most people will not pull the lever and therefore fall on the side of the deontological theory. MRI scans show that the areas of the brains associated with emotions light up when these people considered the question. Their thinking goes that to pull the lever knowing about the one person on the side track would be to take an action intended to kill the one. Deliberately acting to use one person to benefit five others is considered wrong, irrespective of the outcome. Here, standing by and doing nothing is acceptable because as there isn't an act, there can't be a 'wrong' deliberate intention. The death of the five is only an unintended side effect of doing something perfectly acceptable: nothing. But a minority feels very strongly that consequentialism is preferable and MRI scans of their brains show more stimulation of logical reasoning areas when considering the problem. They would pull the lever because one death is a much better outcome than five deaths, and whether there was a deliberate intention to kill or not is irrelevant – only the outcome matters. Similarly, if we think back to our earlier scenario of the passenger travelling on the mountain road, then consequentialist theory would claim that it makes sense for the car to kill them because two children

"In the world of law, judges have to recognise that some actions they don't agree with are still morally acceptable"

PHOTOS: GETTY, ALAMY



Autonomous cars could pick up traffic data in real time, negotiating you through the jam safely

PHOTO: HERE.COM

would be saved. And saving two lives is preferable to saving one.

Acting in accordance with either theory is considered to be ethically principled behaviour. In the world of law, judges have to recognise that some actions they don't agree with are nonetheless still morally acceptable. Respecting others' ethical reasoning is one way we recognise and treat other humans as moral agents with equal status to ourselves. This is an important – although subtle – part of our Western ethical consensus today, because we believe that being faithful to our ethical beliefs contributes towards our well-being.

This makes the problem more difficult for designers of autonomous driver software: there isn't a single moral standard expected of human drivers in these dilemmas. Whichever theory they choose, they will end up offending the morals of ethically principled customers who favour the other theory.

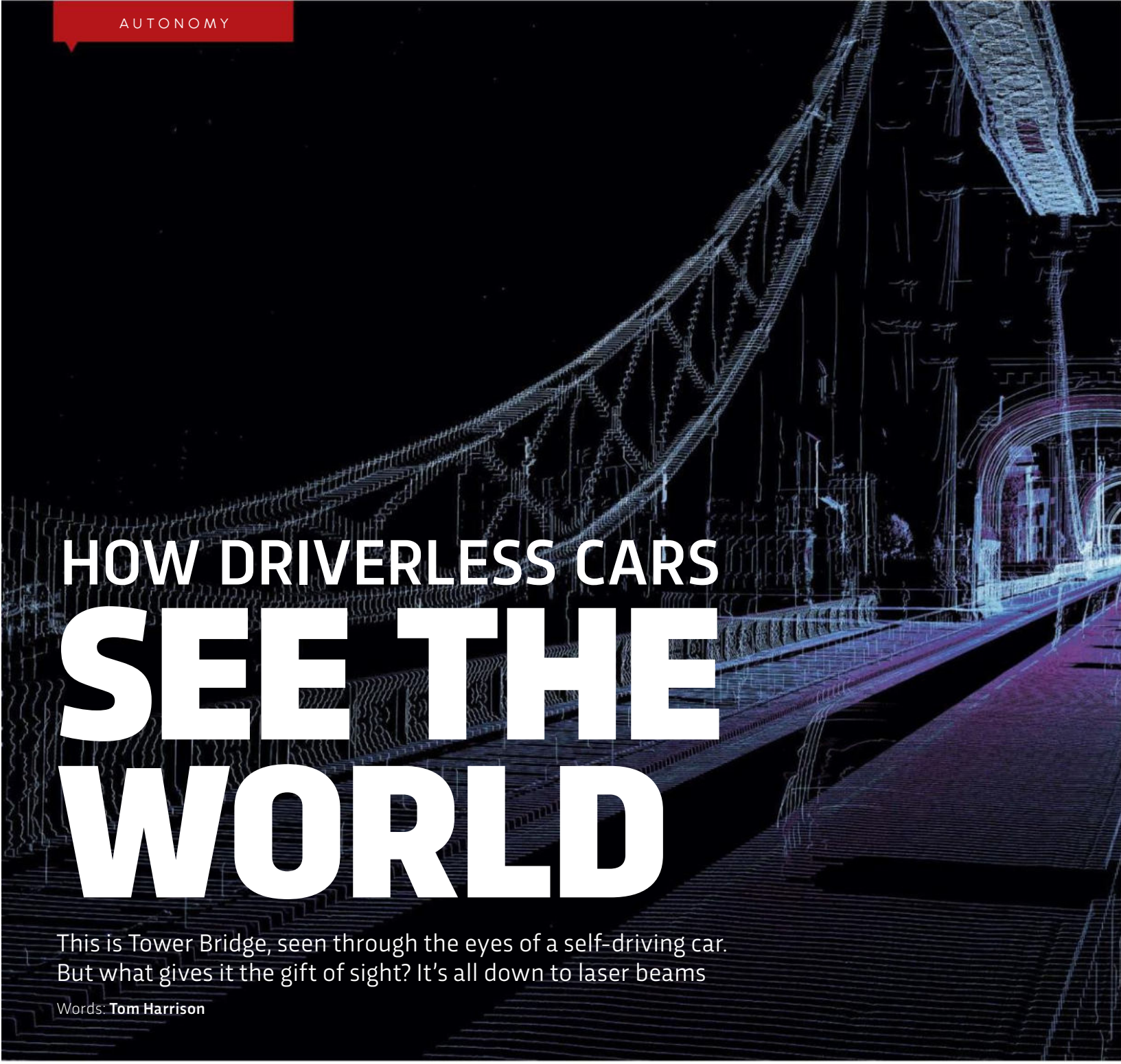
Imagine, purely speculatively, that engineers tend to fall in the consequentialist minority and therefore design consequentialist driver software. However, imagine that the majority of customers are deontological. The engineers would have imposed their own moral preferences on many people who do not share the same ideologies. Being true to one's moral convictions is an important part of human well-being, so we run the risk of inadvertently breaking a moral principle of our societies and adversely affecting the well-being of other people.

I co-authored a paper with Dr Anders Sandberg, an expert in ethics and technology. In the paper, we suggested we could get around the problem of different principles by developing code that would follow either consequentialist or deontological reasoning in a trolley problem scenario. The passenger could selected their chosen principle at the start of their journey. This would preserve the basis of respect for moral agents that allows our society's ethical and legal system to deal with the two different ways that people make their decisions about trolley problems.

We can't have a piece of code that decides between the theories for us. Human moral preferences seem to be a result of learning through praise and blame, not logic. For now, we have to leave that choice to human users of technology. Until they become moral agents in their own right, autonomous cars will act as what Sandberg has called a "moral proxy" for the users' own human morals. In other words, we will select how they choose to act.

DISCOVER MORE

Watch a clip from *A History Of Ideas* that explains the trolley problem at **bbc.in/11pq3pK**



HOW DRIVERLESS CARS SEE THE WORLD

This is Tower Bridge, seen through the eyes of a self-driving car. But what gives it the gift of sight? It's all down to laser beams

Words: **Tom Harrison**

Like SONAR and RADAR, LiDAR – light detection and ranging – is the detection of objects using a signal's 'time of flight' (sound for SONAR, radio for RADAR and light for LiDAR). The principle is easy enough to understand – a rangefinder emits a laser pulse, then uses the time taken for it to bounce back to calculate the distance of an object from the source of the pulse. Take Velodyne, supplier of LiDAR equipment to Ford and Google, at least before the tech giant developed its own. Its flagship HDL-64E scanner has 64 lasers, and the whole body spins at up to 1,200 revolutions per minute for a true 360-degree field of view.

LiDAR scanners like the HDL-64E produce something called a point cloud, a real-time, 3D video of sorts, where each point is the moment a signal is reflected back at the scanner. It's these point clouds that allow an autonomous car to 'see' its surroundings and, with added inputs from a suite of other sensors and technologies (GPS, RADAR, and so on), know where it is and how to behave. The HDL-64E maps 2.2million points per second, with a range approaching 120 metres depending on the reflectivity of the objects in question, accurate down to less than two centimetres. But it's big: 11.1 inches tall, to be exact, and far from cheap, at around $75,000 a pop.

Therefore, the next big thing for autonomous vehicles is smaller, cheaper LiDAR. Velodyne's 360-degree Ultra

PHOTOS: SCANLAB PROJECTS, FORD, ALAMY

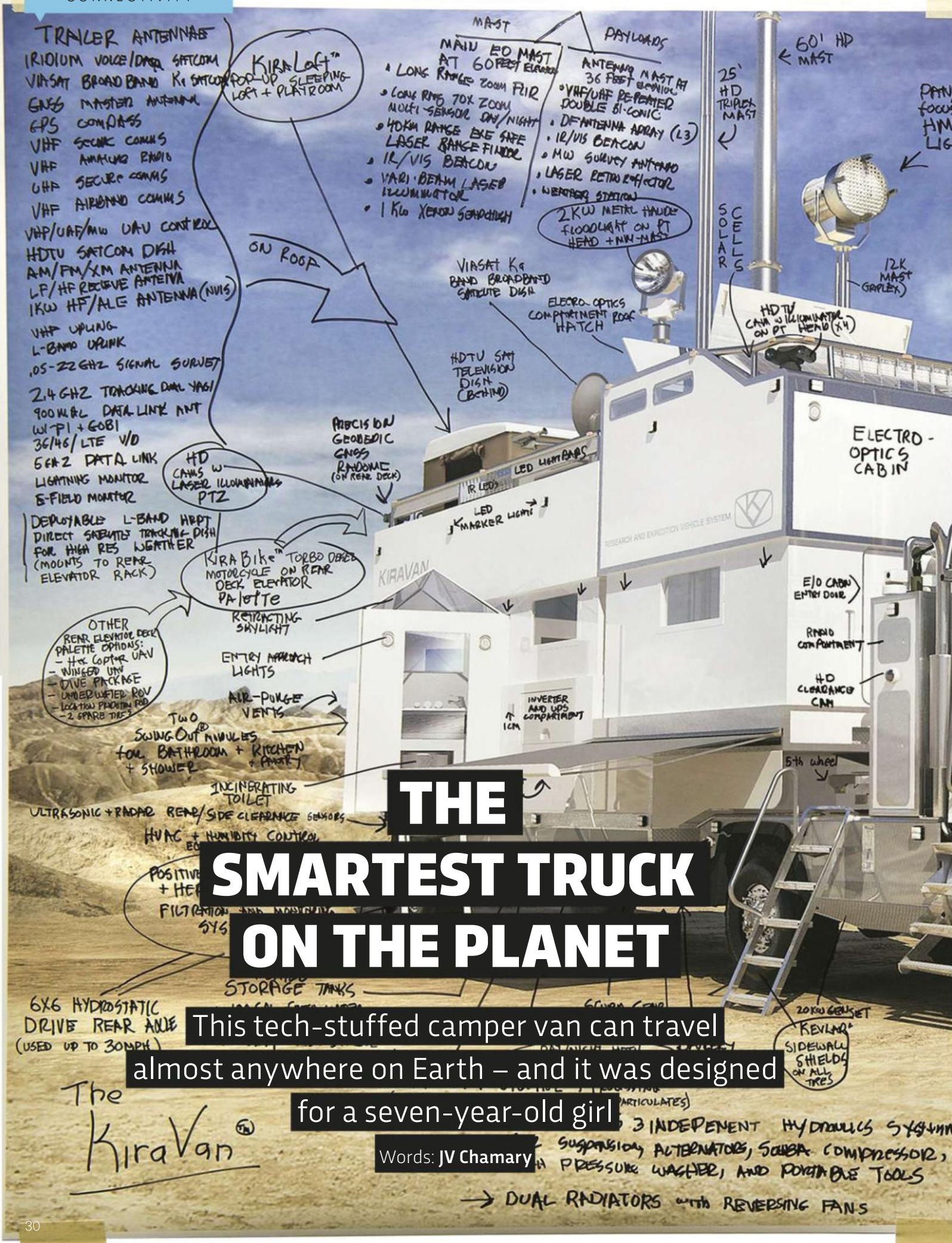
ELON SAYS...

Of course LiDAR is not without its limitations, but some have gone so far as to question whether it's even strictly necessary. Tesla's Elon Musk, for example, reportedly thinks LiDAR is surplus to requirements, and that it "doesn't make sense" in an autonomous car.

Puck is a solid-state hybrid device, like the 64E – which means it combines a solid-state scanner with a spinning body for that 360 degree FOV. It's a 32-channel scanner no bigger than a couple of hockey pucks stacked one on top of the other, with a massive 200m range, 1.2million points per second resolution and a $500 target price when produced in vast quantities.

Quanergy, on the other hand, says its S3 will cost less than $250 per unit if it's produced in big enough numbers when it hits the market in 2017. The S3 doesn't spin – it projects its lasers through an optical phased array, which spears them off in all kinds of directions about a million times a second.

This means it can in theory 'focus' on objects of interest – like a wayward pedestrian or a cyclist with a dubious sense of direction. And while its field of vision is limited to 120 degrees – so an autonomous vehicle would need a few – it is small enough to fit in the palm of your hand.



THE SMARTEST TRUCK ON THE PLANET

This tech-stuffed camper van can travel almost anywhere on Earth – and it was designed for a seven-year-old girl

Words: **JV Chamary**

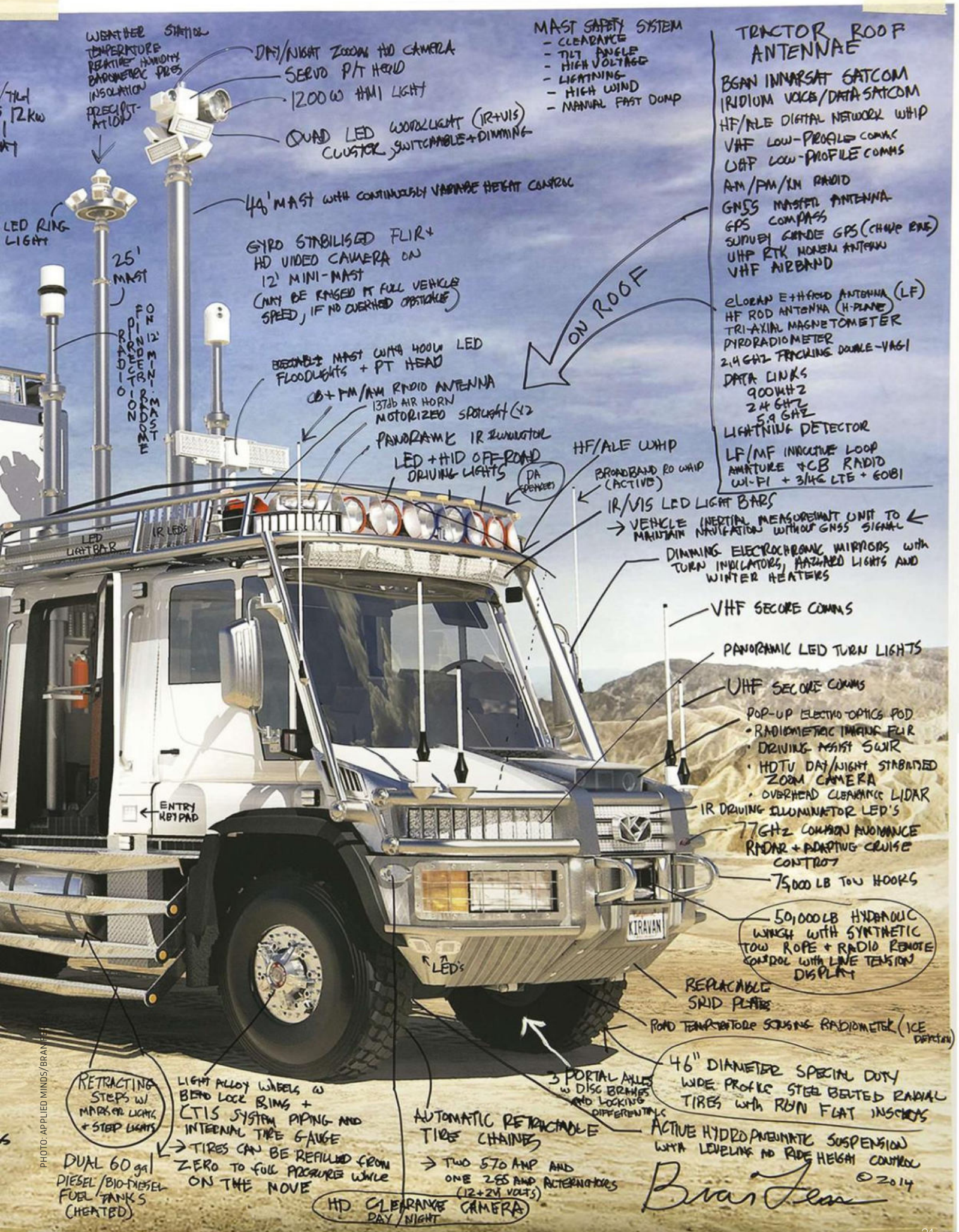


PHOTO: APPLIED MINDS/BRIAN FEA

A HIGH-TECH HOME FROM HOME

Detailing the technology and design that makes KiraVan such a unique vehicle...

NAVIGATION
Receivers for global navigation satellite systems keep track of the KiraVan. But if satellite signals aren't detected, fibre-optic gyroscopes and precise accelerometers record the truck's position, direction and velocity to continue mapping its location.

COMPUTERS
There is an office space with two networked computers, Wi-Fi for portable devices and access to the KiraVan's computer systems. A 4K monitor can act as a graphics terminal to view maps or edit video, while a media library and satellite TV offer entertainment.

SENSORS
Telescopic masts with pneumatic servos control the height of external sensors, which include long-range optics such as infrared and night-vision cameras. The tallest mast can raise those electro-optical systems to 17m above ground level.

COMMUNICATIONS
Satellite communication provides wireless broadband at up to 10Mbps download and 5Mbps upload speeds, working in most areas globally. When satcom services aren't available, the KiraVan uses an antenna for line-of-sight propagation via VHF or UHF radio signals.

COCKPIT
So-called 'glass cockpits' developed for aircraft can now be found in land vehicles such as the Tesla Model S. The KiraVan's cockpit system is far more sophisticated than a passenger car dashboard, with control and instrument panels across no fewer than 11 displays, including six touchscreens.

TRAILER
The trailer shares power and other systems while attached to the tractor, but can also operate as an independent base station. It's made from composite materials such as aramid and fibreglass, and its walls offer radio-frequency shielding and lightning protection. The main sleeping loft is on a balcony, below a pop-up 'penthouse' tent. The kitchen and bathroom areas are expandable, increasing the internal volume by 50 per cent.

ENVIRONMENT
Whether it's -35°C or 55°C outside, a heating, ventilation and air-con system keeps everything comfortable.

KIRABIKE
The KiraBike is mounted on an elevator at the trailer's rear. This motorcycle serves as a 'dinghy' for short trips, and features an unusual (for a motorbike) three-cylinder diesel engine with 100mpg fuel economy. It has VHF and UHF radio for communication and includes a rugged tablet for internet access.

WHEELS
Each Kevlar-reinforced Michelin tyre is 116cm (46in) wide and weighs 135kg. Strong yet light alloy rims allow the tyres to run flat, while a self-inflation system can refill them in under five minutes. Tyre chains can be deployed for traction on slippery surfaces like ice, even while the vehicle is in motion.

POWER
A six-cylinder, 260bhp diesel engine (with 700lb ft torque) powers the tractor, while 650-litre tanks supply it with enough fuel for a 3,200km driving range. In the trailer, a 25kW diesel generator transfers mechanical energy to five alternators to create electric current, helped by solar power.

TRACTOR
The tractor is a Mercedes-Benz 'UniMog' truck with a stretched and strengthened chassis. While on the road it has permanent four-wheel-drive and a top speed of 112km/h (70mph). Off-road, a hydrostatic system can also send power to the rear axle for six-wheel drive up to 40km/h (25mph).

SUSPENSION
Instead of conventional springs or shock absorbers, the KiraVan uses a nitrogen-over-oil system controlled by computers. As in many off-road vehicles, the suspension is attached to portal axles (the tube is above the centre of the wheel hub) for increased ground clearance – good for clambering over rocks.

A touchscreen cockpit, fibre-optic gyroscopes, night vision cameras... the KiraVan Expedition System has it all. This super-smart truck is also the ultimate all-terrain vehicle: a 4x4 that can handle sand or snow, climb hills, cross streams and explore the world's most remote regions. Built for endurance over long distances, the truck can carry enough supplies to sustain a three-person crew for three weeks. If satellite communication isn't available, it can navigate via high-frequency radio signals. A 700-litre tank can be topped up with water passed through a silver-lined anti-microbial, ultraviolet filtration system, while salt water is first desalinated by reverse-osmosis.

The high-tech van is the brainchild of inventor Bran Ferren, who named it after his daughter, Kira. In 2010, Ferren finished converting a Mercedes-Benz UniMog truck into a 'MaxiMog' with extras like cameras and videoconferencing. His daughter was born while he was planning the MaxiMog's successor, which Ferren says inspired him to design a more child-friendly vehicle.

TOP: The KiraVan can happily traverse just about any terrain our planet can throw at it

ABOVE: The operator's console houses communications equipment, with a joystick and display for operating RC vehicles

LEFT: The galley has all the appliances you need to cook in the wild, and was designed with input from a chef – Kira's mother

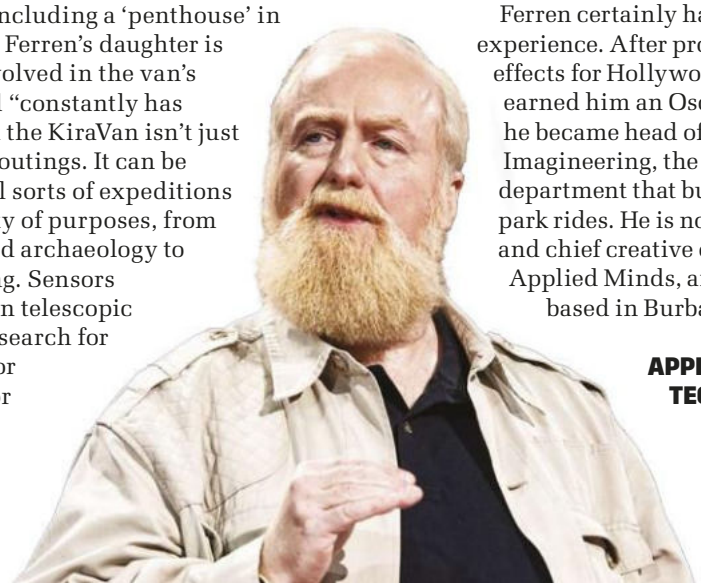
PHOTOS: APPLIED MINDS X3 ILLUSTRATION: BRYAN CHRISTIE DESIGN

"Upon Kira's arrival," he says, "the notion was, well, something that's better suited to a family would be appropriate."

Everything is packed into a modified tractor and trailer that's 16m long and weighs up to 23.5 tonnes (limited to 19 tonnes off-road). It has areas for Kira to work and play, including a 'penthouse' in the trailer. Ferren's daughter is closely involved in the van's design and "constantly has input", but the KiraVan isn't just for family outings. It can be used for all sorts of expeditions for a variety of purposes, from geology and archaeology to filmmaking. Sensors mounted on telescopic masts can search for dig sites, for example, or capture images for a high-resolution gigabit panorama.

"It's designed to support a very flexible range of activities," says Ferren, who believes in testing tech himself. "If you're going to actually design, engineer and build things, you need to have your own first-hand experience with them."

Ferren certainly has the experience. After producing special effects for Hollywood, which earned him an Oscar nomination, he became head of Walt Disney Imagineering, the R&D department that builds theme park rides. He is now co-founder and chief creative officer of Applied Minds, an R&D firm based in Burbank, California.



APPLIED TECHNOLOGY

Ferren's vision for KiraVan is implemented by a team of 30-40 employees, which can rise to 100 when specific skills (such as welding) are needed to bring hardware together. Anticipating that certain things, such as computer software, will no longer be state-of-the-art by the time Kira is old enough to drive, Ferren has made the van modular so it's easy to upgrade. If a component is likely to go obsolete sooner rather than later, it's designed in such a way that it's straightforward to swap out.

Applied Minds is also using the KiraVan as a platform for research projects. Testing technologies might mean adapting sports car parts or creating something new. "The vast majority of the time, standard technology won't do," Ferren explains. "There are dozens and

LEFT: In the cockpit, switches and screens over the windscreen control external sensors and lights, while the central console is for driving

BELOW: This is Bran Ferren's sleeping area. The ladder leads to his daughter's bedroom above

RIGHT: The KiraVan has many attributes and abilities. Stealth, though, isn't really one of them

BELOW LEFT: Bran Ferren , who made the vehicle for his young daughter

dozens of unique things on the vehicle, and each of them presented a creative, technical and often aesthetic challenge."

One such challenge is balancing on-road and off-road performance, as there's a trade-off between driving on highways, when a low centre of gravity helps, and handling rocky terrain, which requires high ground clearance. Ferren also points out that, like all modes of transport, the van needs to cope with turbulence. "It's more complicated designing a vehicle like this than a plane or a boat," he says.

Ferren compares his creation to another luxury vehicle: a yacht. Both are custom creations that are expensive to make because they can't benefit from the economies of scale afforded by mass production. The KiraVan has cost millions to develop, but it's impossible to put an exact figure on how much, partly because the tech that Applied Minds develops is licensed to the firm's clients, which subsidises the Ferren family's personal camper van.

Applied Minds is preparing to test the KiraVan in the extreme heat of Death Valley this summer, and Ferren estimates that the truck is 80 per cent complete and should be ready to roll in about a year's time. So once it's finished, where does Kira want to explore first? "It's not like she wakes up in the morning and says, 'We need to go to the Grand Canyon'!" says Ferren. But he adds that his own parents were artists with wanderlust. "That desire to travel and see the world and experience other cultures definitely transferred to me, and hopefully it will to her as well."

JV Chamary is a freelance science and technology writer based in Bristol.

PHOTOS: APPLIED MINDS/BRAN FREEN X3, JAMES DUNCAN DAVIDSON/TED

Electroencephalography (EEG) uses electrodes to monitor electrical activity of the brain, and it could help your car read your mood

PHOTO: ALAMY

MIRROR, SIGNAL, MIND CONTROL

From the highs of a fast blast to the lows of rush-hour gridlock, driving can be an emotional business. If only our cars knew how we were feeling

Words: **Stephen Dobie**

The more connected our cars become, the more they'll get to know us. Like it or not, and as they're increasingly entwined with social media, they will build an impressively accurate picture of our lives – mapping where we've been, when we went, how quickly we travelled there, and what music we listened to on the way (let's hope they don't develop a sense of humour, eh?). This will allow them to predict our destination, our route and even our mood, based on habits and hard data. But what if they could go a step further? Could the car of the future actually read your mind? What sounds like a slightly terrifying vision of a sci-fi future isn't as far-fetched as you might think.

The relationship between man and machine has already blossomed in the world of bionics, where the most advanced and complex prosthetic limbs can be controlled by the power of thought. And it appears the car world has been taking notes.

First, let's look at a really adventurous idea. Researchers at Nankai University in China have spent two years developing a car that can be driven entirely by the human mind. The driver wears a brain-reading headset, which contains 16 sensors that collect an electroencephalogram (EEG scan). It then wirelessly transmits the data to a computer, which translates these signals into simple commands that are fed to the car's controls. It's intended to work alongside autonomous tech, and the user's

ABOVE: **Who needs a steering wheel when you can control your car just by thinking the commands?**

thoughts are only required when the car needs to change direction, rather than a constant flow of brain activity to keep it from crashing. It's intended to give disabled drivers a better transport option, but expect a long wait – trials have only seen a car drive in straight lines thus far, and there are no production plans for now.

MOOD MONITORING

What we can expect within ten years is Jaguar Land Rover's 'Sixth Sense' technology. Bringing in research from medicine, sport and aerospace, it looks to dig into the driver's psyche to make driving safer. Best of all, it involves mind reading. "One key piece of new research is to see how we could measure brainwaves to monitor if the driver is alert and concentrating on driving," says JLR's Director of Research and Technology, Dr Wolfgang Epple. "Even if the eyes are on the road, a lack of concentration or a daydream will mean the driver isn't paying attention to the driving task. We are looking at how we could identify this and prevent it causing an accident."

So brainwaves – as well as heart rate and respiration levels – will be monitored, and a picture of stress, fatigue and concentration levels built up. At one end of the scale, the car will adjust the interior temperature and lighting to keep your mood in check, or suggest pulling over for a break. At the other end, a car with autonomous capabilities would identify a cardiac arrest, take over driving, and call the emergency services to save the driver's life. It's something JLR dubs 'Driver Wellness Monitoring'.

The heart rate and respiratory systems are comparatively simple: sensors in the seats monitor what's going on inside you and feed the info to the car's functions. The brain scanning is trickier. When *BBC Focus* gave it a go on a simulator, we had to wear a device so the 'car' could perform its EEG upon us, the results of which appeared on a screen, allowing us to see exactly which brainwaves we were producing. By the time the tech lands, hand sensors on the steering wheel (or wearables such as Android watches) will avoid the need for the ever-so-slightly demeaning head gear.

Our brain waves (see right), predictably, reveal a lot about our state of mind. Just for fun, we were given the task of 'thinking' the simulated car around a road; if excessive Delta and Theta waves were picked up by the EEG, the car would go off course.

PHOTOS: GETTY, DARPA

We were given other things to do while 'driving', such as using a phone or holding a conversation. The drop in attention picked up by the brain scanner was stark, showing just what potential this tech possesses. The idea is that the car would alert the driver or take over altogether if attention dropped significantly.

Predictably, JLR isn't alone in developing this sort of technology. Ford has researched in-seat health monitoring in the past, but halted development as wearable tech took off, while that's an advancement Audi is using to its advantage with the 'Fit Driver' programme, which the firm says will enable future drivers to "leave their cars more relaxed than when they entered them". A watch or wristband would read heart rate and body temperature, while sensors in the car would collect breathing rates and monitor your driving style and outside conditions. The climate control, massaging seats, lights and infotainment would then adjust to create an appropriate mood.

Assessing traffic ahead would mean the car could suggest optimal places to stop for a break, while it would also provide 'biofeedback' in the form of suggested breathing exercises. For the uninitiated, what sounds like a yoga class on the move might perhaps prove more stressful.

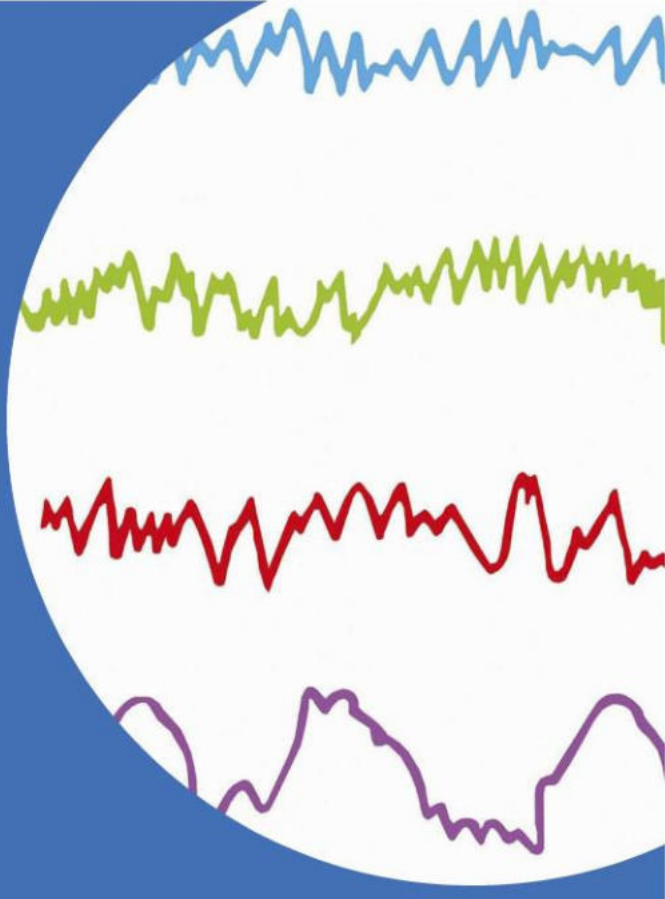
RACING INTO THE FUTURE

As piloted driving technologies become common, there's certainly a lot of sense in your car knowing when you're not feeling sharp. Like JLR, Audi sees the technologies working hand-in-hand to save lives, and has also spotted potential in the data collected by the car being sent to external devices, or to smart homes able to prepare themselves for the arrival of a stressed driver.

In the world of motorsport, McLaren's MP4-X racing car concept is looking at how biotelemetry could benefit drivers, keeping an eye on fatigue and hydration levels, while giving spectators yet more insight into the cockpit. The car's functions could also operate via brain synaptic control, de-cluttering the mess that is a modern F1 steering wheel. "The tech for this sort of thing is still in its early stages," says McLaren, "but it could be possible." McLaren has a strong relationship with UK pharmaceutical company GlaxoSmithKline, and has been working on neurological science advances since 2011.

It was neural implants, of course, that allowed America's Defence Advanced Research Projects Agency (DARPA) to bring mind control to prosthetic limbs. There's a heck of a lot of research still to go, not least into how the brain and computer adapt to each other. And then there's the small matter of reducing the circa-$400,000 cost per limb if it's to become a commercial possibility, too. But the benefits they could bring their users is impossible to overstate, and it's proof that mind-reading tech shouldn't be labelled as conceptual whimsy; it holds life-changing potential.

PHOTO: GETTY



GIVE US A WAVE!

Want to drive using only the power of thought? Time to get your brain in gear

There are numerous brainwave bands, but the four key to mind-reading cars are Alpha, Beta, Delta, and Theta. If Delta and Theta are particularly prominent, the brain is in a relaxed state, and possibly daydreaming. Delta is linked to a deep, dreamless sleep, while Theta is active during dreams (be they good or bad) and meditation. Alpha waves are also linked to relaxation, but – running at a higher frequency – they're the sort that yield calm yet alert mental activity and good hand-eye coordination. Beta waves are quicker still, and appear when we're engaged with problem solving. Over-arousal of any wave type results from anxiety, anger, or other negative states of mind. Not to mention, of course, any chemical interventions from alcohol or drugs. Could cars of the future identify illegal quantities of them? It's an interesting proposition.

THE VIRTUAL BUTLER BY BENTLEY

You know you've made it in this world when you can spec your brand-new limo with an imaginary friend

Words: **Dan Read**

British luxury car manufacturer Bentley is associated with classicism, grandeur and a certain regal sophistication. A Bentley is a sign that you've made it in life, and that you're in a position to be served rather than serve. But how will this work in the future?

In March this year, Bentley unveiled its answer – a concept so ostentatious it comes with its own holographic butler. OK, Bentley hasn't created a posh Rimmer who'll physically complete your commands; instead, your virtual servant is there to offer you guidance as well as, er, company.

"Luxury is always related to service," explains Bentley's design director Stefan Sielaff. "People don't like the idea of just talking to a hidden microphone. We are thinking of how to personalize the next generation of communication."

So your holographic Jeeves won't serve tea, but he might try some light marriage counselling, or at least phone ahead so the hotel can clear a space for your luxo-barge.

THE WORLD'S FIRST CAR PHONE

We tend to think of the connected car as a very modern, very digital concept. But we've actually been toying with the idea for 70 years...

Words: **Dan Read**

In 1946, a driver in St Louis placed the very first call from the world's very first car phone. The phone, if you can really call it that, was actually a Bell System police-style radio fitted with a telephone handset and a 'selective calling decoder', which rang a bell in the car when it detected a particular pattern of radio waves – its 'phone number' – being transmitted by a caller's device. The above image shows it being demo'd by a Bell Systems rep.

This rather primitive VHF system, and others like it, were the basis for the next three decades of car phone tech, but despite constant development, users faced increasing network congestion and often had to wait minutes to place a call.

Things started to change in the 80s, with the rise of cellular mobiles. In 1984 Motorola released the legendary DynaTAC, a white brick sported by any banker worth his pinstripes. Two years later it launched the the 4500X – one of the first and most famous car phones, although it weighed over four kilos including the battery, and to get much signal in the UK, you'd have to drive to London. Then came the smaller, digital mobiles of the 90s, but the real connectivity revolution came when hands-free Bluetooth tech arrived in 2000. A year later, and for the first time, mobiles could be paired to a car's audio system, or – if your car didn't have a posh infotainment system – to an earpiece that made you look a bit ridiculous.

PHOTO: AT&T ARCHIVES AND HISTORY CENTER

REALITY CHECK

With see-through bonnets, ghost cars and widescreen movie projections, our view of the road is about to change forever

Words: **Stephen Dobie**

PHOTO: JAGUAR LAND ROVER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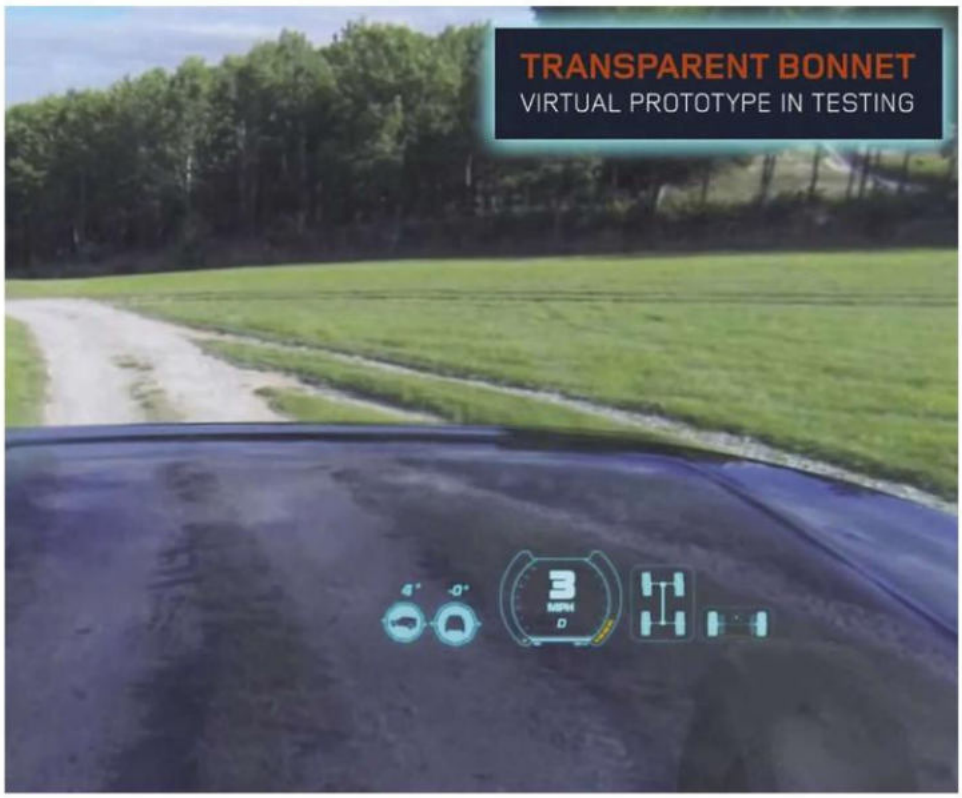


ABOVE: **Land Rover's 'transparent' bonnet means you'll know exactly what you've just run over...**

Of all the features on today's cars, there's one we rarely talk about – a huge widescreen, one that's no doubt bigger than your television. At the moment, its primary roles are twofold: being transparent, and stopping bumblebees from hitting your face as you blast along the motorway. But a tranche of new technology means the humble windscreen is about to work much, much harder.

It's all thanks to augmented reality. We're familiar with it in other contexts, but it can also benefit the motoring world in many ways, the most interesting of which are being pioneered in Jaguar Land Rover's technology lair, where endeavours are slanted towards safety – both the active avoidance of accidents, and the passive benefits of a de-stressed driver.

For example, Land Rovers of the near future will have see-through bonnets. Cameras strategically placed around the outside of the car will capture the things the driver can't see, and feed them into a windscreen head-up display that, from the driver's point-of-view, makes the engine and its cover appear to be invisible. The vehicle's extremities stay in sight – so you know where to thread them – while some virtual wheels are projected so you can point the real ones in the right direction.

There's more to this beyond showing off. Over to Dr Wolfgang Epple, JLR's Director of Research and Technology. "We are developing new technologies including the Transparent Bonnet to give drivers an augmented view of reality, to help them tackle anything from the toughest off-road route to the tight confines of an urban car park," he says.

It's a boon if you're off-roading, then, making it considerably less buttock-clenching when you're clambering over tyre-piercing rocks or through narrow gaps. But on the road, where 99 per cent of SUVs actually live, the ability to make multi-storeys and width restrictors less of a potentially pricey assault course is more likely to impress.

Of course, this is also confirmation that JLR's cars are among a vast array that are gaining in size and ceding visibility with each generation. But its fondness for showcasing ideas while they're still in development suggests its solutions to those problems will appear sooner, rather than later.

EYES ON THE ROAD

Another innovation comes in the shape of windscreen-wide versions of the HUDs common today, which tend to be focused on one small area.

"If we can keep the driver's eyes on the road ahead and present information in a non-distracting way, we can help drivers make better decisions in the most demanding and congested driving environments," says Dr Epple.

So there'll be see-through A-pillars (making it easier to peer out of junctions), large on-screen displays pointing you to empty parking spaces to save you taking your eyes off the road, as well as a 'ghost car' that will lead you to your destination.

PHOTOS: JAGUAR LAND ROVER, AUTOGLASS, GETTY

ABOVE: **HUDs of the future won't just project basic information, they'll also pick out hazards such as men in red scarfs**

How will that work? Essentially an AR car – a bit like the ones in the Time Trial sections of driving simulation games – will appear on the road ahead (or rather, on the windscreen), and you'll follow it as if you were following a friend that knows the way. Given how easy it is to misinterpret even the best sat nav instructions, the potential stress relief is something we can't wait to sample.

There's not only safety potential here, though. JLR has shown a version of the augmented screen which displays lap times and target driving lines when you're on a circuit. McLaren, meanwhile, sees benefits for motorsport. Its MP4-X racing car concept demonstrates an advanced head-up display that warns drivers of debris, warning flags, and the positions of competitors.

Put an active windscreen hand-in-hand with driverless car technology, meanwhile, and Nissan sees it as a fun way to pass the time when the car's doing all the work. "One day, you could use the car as the computer game simulator," says the firm's head of Advanced Product Strategy, Richard Candler. "While the car is driving you to work, you could be using it as the controller to drive round the Nürburgring on your PlayStation, adding a bit more fun to people's lives." And a bit more motion sickness, we imagine.

But shouldn't we be careful that this stuff doesn't become too gimmicky? "Keeping the technology relevant is key," says Chris Davies from Autoglass. His company is monitoring the work of manufacturers via its Vision 2020 programme, so its knowledge on how to replace windscreens keeps up with the tech embedded within them. "Anything that's going to be a risk to distraction shouldn't be on the screen when you're moving," he says.

INFORMATION OVERLOAD?

The driver's attention span could certainly become an issue when it comes to how much information should be displayed. As an example, Samsung's idea of linking a smartphone to a motorcycle screen could put too much of a moral dilemma into the rider's hands. But Davies reckons there's plenty of time to suss this stuff out. "I reckon 2023 is when true AR will come in. Whether it's projected onto the screen or built into it, via OLED, is hard to say at the moment."

Augmented reality will affect the car world away from the road, too. Hyundai has showcased an AR owner's manual, which, using your phone, guides you around the interior and under the bonnet in accordance with where you point the lens. It'll help you replace simple components, and determine what all the buttons and warning lights relate to. So sensible, you wonder why it's arrived only now, this far into the smartphone's life.

Going a step further, into the world of virtual reality, JLR is using VR headsets to help design its cars' interiors, bringing CAD designs to life to ascertain their usability before costly materials are used on physical mock-ups. And you could buy your next car with this VR tech. Audi has made the online configurator a full-size plaything thanks to VR goggles (see p114), while Google's Project Tango technology means a headset-less AR version isn't far away. Pick your colours and options, see the car materialise before you, and have a poke around. Short of standing in the factory's paint shop, there can't be a better way of perfecting your car's spec.

Augmented reality may not grab media attention quite like autonomous driving does, but with existing tech at its core and significantly fewer legislation worries, there are fascinating results just around the corner.

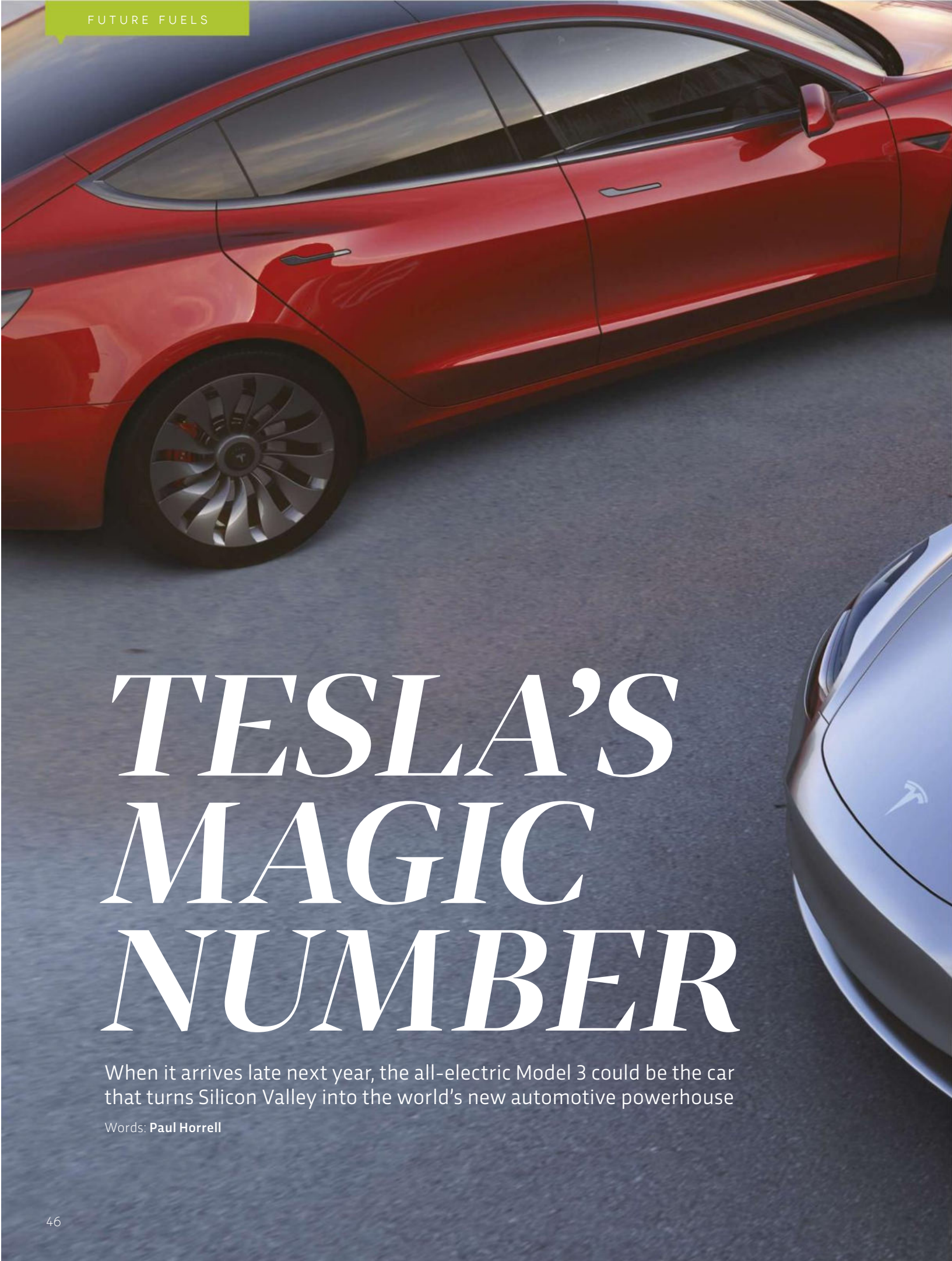
THANKS FOR THE HEADS-UP

Our best taste of augmented reality in cars right now is the head-up display. Its origins lie in aviation – the first airborne HUD appeared in 1958.

It took until 1988 to arrive on ground level, though, in the Oldsmobile Cutlass Supreme. We'll forgive you for not recognising a niche American model, which was a surprising entry point for such desirable tech.

The Cutlass's HUD was a digital speedometer, projecting a display not unlike that of a bedside clock radio onto the windscreen. First available on a special edition spun from the 1988 Indy 500 Pace Car, it made its way into other models afterwards.

BMW brought HUDs to the European mainstream in the mid 2000s, and now everything from a Mazda and Mini upwards has one on the options list. It's common sense tech that can also make you feel rather *Top Gun*. We like that a lot.



TESLA'S MAGIC NUMBER

When it arrives late next year, the all-electric Model 3 could be the car that turns Silicon Valley into the world's new automotive powerhouse

Words: **Paul Horrell**

ABOVE: **It might look like a hatchback, but the 3 is actually a saloon with a good ol' trunk. That's a boot, if you're English**

The Tesla Motors story is the most remarkable thing to have happened in the car industry for decades. The Model 3 is the culmination of Tesla's mission laid out soon after the company's 2003 foundation: a fully-electric car that does the same job as a mass-market family saloon with a combustion engine, for a similar price.

Just eight years ago, almost no-one had heard of Tesla and it hadn't sold a single vehicle. The same year, we ran an article in *BBC Focus* on 'the car of 2030', which involved interviewing many very senior motor industry engineers and futurologists. The article said: "Pure electric cars will be well developed by 2030, but it's still unlikely they will have the battery capacity or quick-charge ability to make them useful over long distances."

Yet in just five years, Tesla had completely upended both those assumptions. It was selling a fast and luxurious saloon, the Model S, that could do 250-plus miles on a single charge. And it was rolling out a network of fast-charge 'Supercharger' stations that could supply the car with about another 150-170 miles' worth of energy in just 30 minutes.

Oh and almost as a by-the-way, a couple of years after that, Teslas were able to drive themselves on motorways and main roads, negotiating other traffic and following white lines while their drivers YouTubed themselves reading the newspaper – although the legal disclaimers say the driver must be ready to take control at any instant.

"Even the lowest performance version will do 0-62mph in less than six seconds"

WHAT'S IT FOR?

At about the same size, and about the same price, as a mid-range BMW 3-series or Audi A4, the Model 3 is aiming at a pool of millions of car buyers worldwide.

The headline figure, the one that makes it tenable as a car that's useful for more than just local commuting, is the range: at least 215 miles in the standard (and fairly realistic) US test. That's the cheapest version, though higher-capacity battery packs will available – making uninterrupted long trips entirely possible, though it's yet to be confirmed whether the Model 3 will be eligible for free use of Tesla's ultra-quick Superchargers.

PHOTOS: TESLA

ABOVE: There's no need for traditional grilles or air intakes, so the 3 has a nice smooth face

"We don't make slow cars" said Tesla's CEO Elon Musk at the unveiling of the Model 3 prototype. He claimed even the low performance version will do 0-62mph in less than six seconds. "And of course there will be versions that go much faster." He also confirmed there will be an option for all-wheel-drive with an extra electric motor at the front instead of the standard single-motor, rear-wheel-drive version. Self-levelling air suspension will be an option too.

Musk also said 'Autopilot' hardware will be fitted as standard. This includes sensors around the car – radar, ultrasonic and visual – that can read road lines and build up a picture of surrounding traffic and static objects. Tesla also has high-res maps, and the car is connected with Tesla's HQ to update them. On payment of an optional fee, Autopilot is activated, enabling the car to self-drive in many circumstances: cruising with the traffic on dual- and single-carriageways, stopping and starting in jams. It can also drive into and out of tight parking spaces with the driver standing outside.

THE BODY AND INTERIOR

Although the world's media is yet to properly get its hands on a prototype, the cabin is said to be unusually roomy for the size of car. It seats five comfortably, because the instrument panel and front seats are more forward-mounted than usual. That's possible when a car jettisons the space-hogging combustion engine and transmission. A Tesla motor is about the size of a bucket, and simply sits between the wheels. Because of the car's smooth shape, and the fact less cooling air has to pass through the body than with a combustion car, the Model 3 has a drag coefficient of just 0.21. Low drag means low power requirement when cruising, which is vital for the long range.

TESLA: THE TALE SO FAR

Named after a legend, backed by a billionaire. What could go wrong?

Soon after Tesla was founded, it received heavy investment from Elon Musk, co-founder of PayPal and SpaceX. Musk has since become Tesla's CEO and its Chief Product Architect. It's very much due to him that the company has attracted billions in investment for its R&D and production facilities. But the company's vision hasn't actually been to make money in the near term, but rather to save the world from oil-driven cars.

Musk always said that a mass-market car would be an impossible first step. So the first product was a low-investment, high-priced sports car, the Roadster, built with the co-operation of Lotus. Some 2,400 Roadsters were made, from 2008. Sales helped to finance the Model S saloon, sold from 2012. This has been a huge success, its sales running at an annualised rate of about 60,000. Tesla soon added a crossover version, the Model X, notable for its extraordinary 'falcon wing' upwards-opening rear doors. With the huge early interest in the Model 3, Tesla now says it's planning to get to an output of 500,000 cars a year by 2018 – more than Land Rover and Range Rover combined.

Musk says he often stays by the Model X production line, overnight, in a sleeping bag

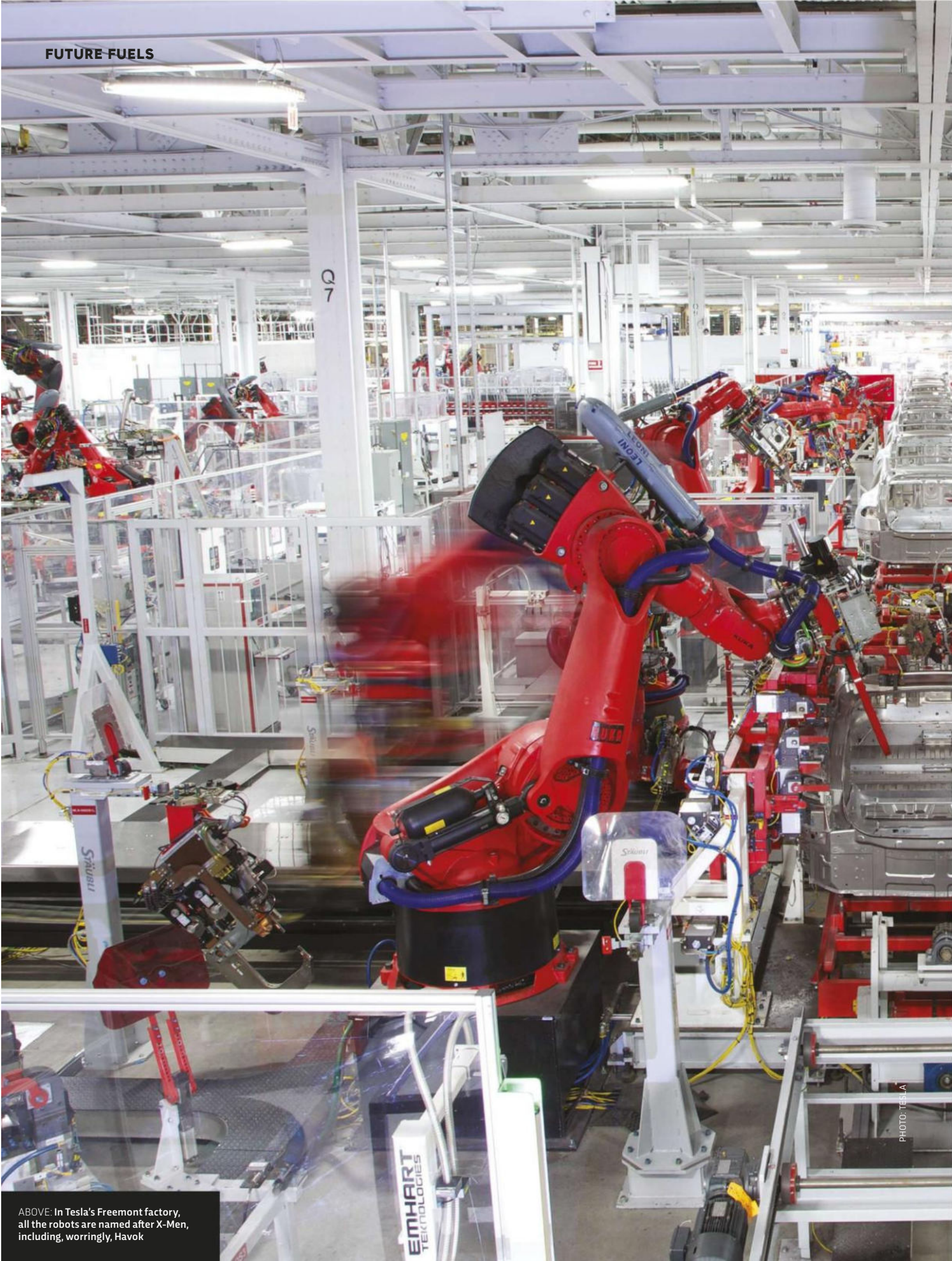
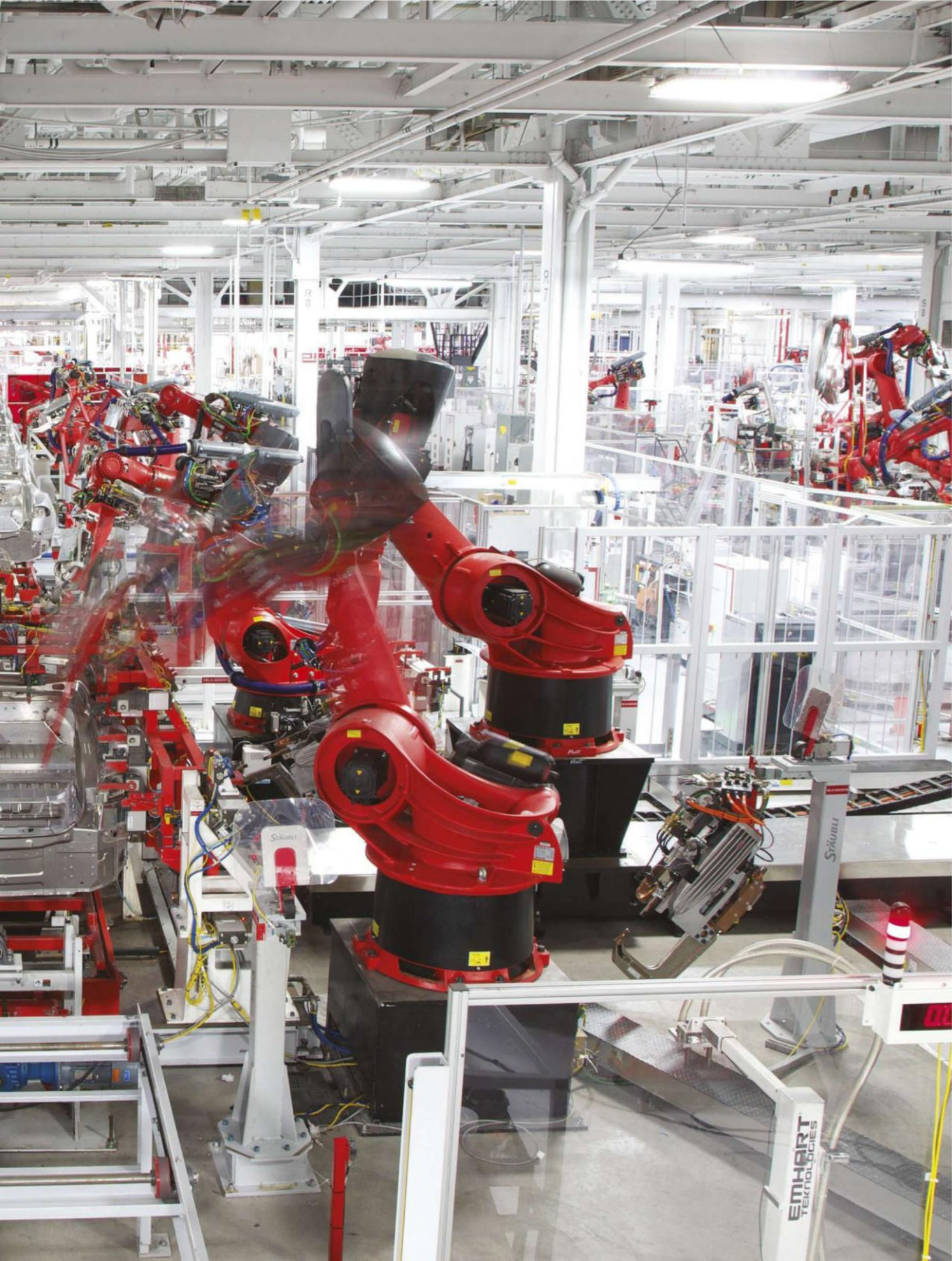


PHOTO: TESLA

ABOVE: **In Tesla's Freemont factory, all the robots are named after X-Men, including, worringly, Havok**


STÄUBLI
EMHART
TEKNOLOGIES

It looks like a hatchback, but the Model 3 is actually a saloon. Rear passengers sit beneath a single glass panel that sweeps rearward to include the fixed rear window. Not having a hard engine in front also helps safety – a high proportion of the space ahead of the driver's feet is a crush zone. Tesla has an enviable record in crash tests. The space in the nose of the car gives a second boot to supplement the one behind. The existing Tesla Model S and X have the same thing. Initially called the front trunk, it's now universally shortened – like it or not – to 'frunk'.

The battery lies in a protective cage under the floor, a rectangle so thin it barely raises the passenger compartment. Anyway, there's no need to find space for a fuel tank, exhaust system, prop shaft or other adjuncts to a combustion engine.

Although Tesla's existing Model S and X use aluminium bodies, the Model 3 will have more steel. It's heavier, but much cheaper when building a car in the numbers projected.

Early pictures showed a minimalist interior with a huge central touchscreen and nothing else in the way of instruments. But we now know this was a prototype, and it's expected the final production version will also feature a head-up display

THE ELECTRICAL SYSTEM

Tesla's battery cells are superficially nothing new. They're very similar to the lithium-ion type that power your laptop. What's so special is Tesla's tweaking of the cell chemistry, and more so the way it builds the cells into batteries, to monitor and care for each individual one of the thousands of cells, keeping them at a critical temperature and carefully managing their charge-discharge process. Both those things are the key to a long life.

"The car's battery cells are very similar to the lithium-ion type that power your laptop"

Another major determinant of battery life is the total number of charge-discharge cycles. Because Tesla gives its cars huge batteries, there are relatively fewer cycles over the car's lifetime than in cars with shorter range. Tesla hasn't given a figure for the Model 3's battery capacity, other than to say it needs less than the one in the Chevrolet Bolt. The Bolt, available in the US a year ahead of the Model 3, has a projected range of 'at least' 200 miles on a 60 kilowatt-hour (kWh) battery. Funny how little credit General Motors is getting for beating Tesla to the market with an affordable, 200-mile electric car, albeit the Bolt's specification shows slightly slower acceleration and twice as lengthy recharging.

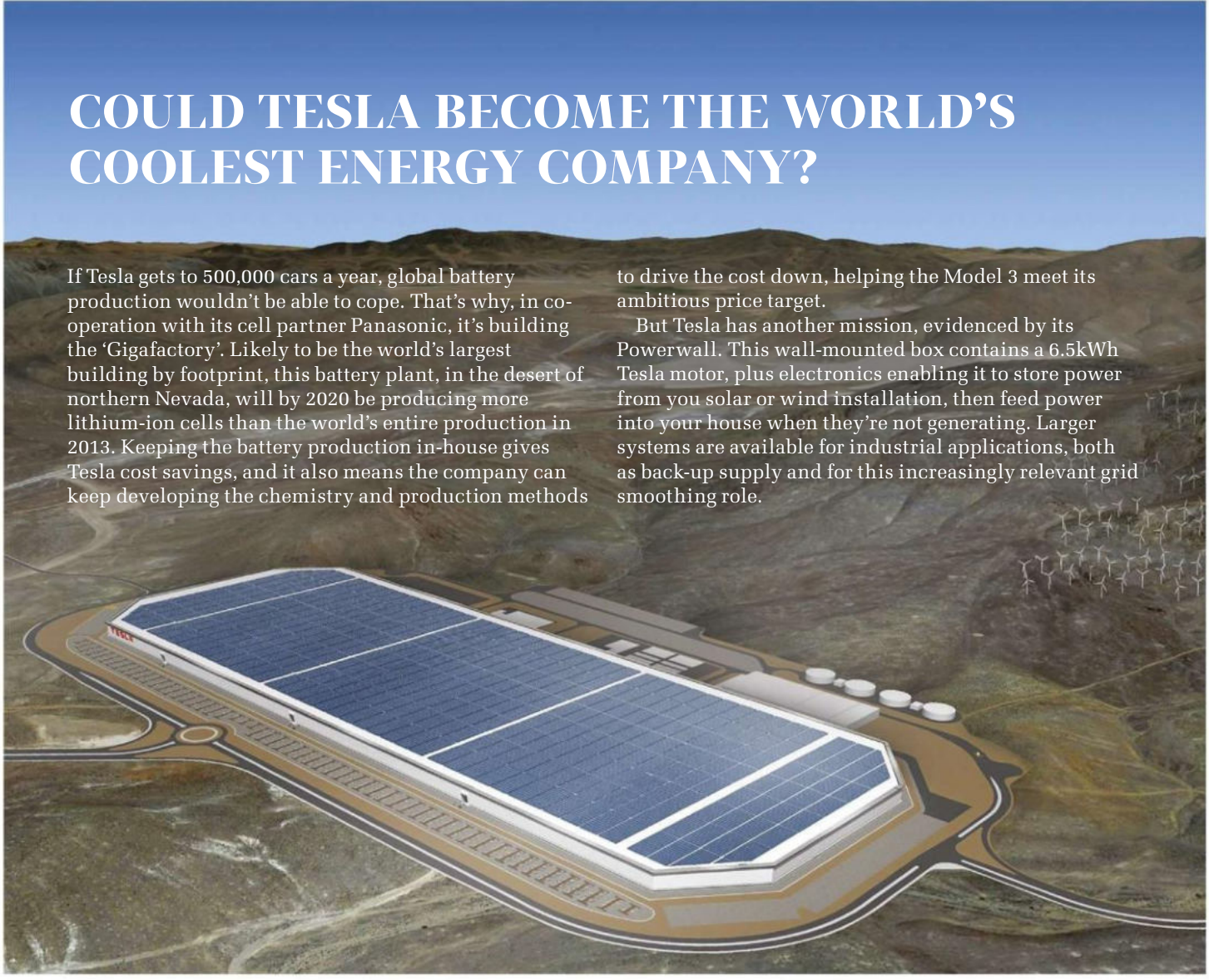
The Model 3 battery's high-voltage DC output is converted by a power electronics module to AC for the main induction drive motor. The company is named after Nikola Tesla, who in 1888 patented such a motor. AC induction motors are proven and robust, but require extremely finely developed electronic control to run with the subtle power variation and wide speed range required of a car whose transmission is a simple single-speed

BELOW: **Fancy a Model 3? Tesla is taking £1,000 deposits via its website, but you'll still have to joing a very long queue**

COULD TESLA BECOME THE WORLD'S COOLEST ENERGY COMPANY?

If Tesla gets to 500,000 cars a year, global battery production wouldn't be able to cope. That's why, in co-operation with its cell partner Panasonic, it's building the 'Gigafactory'. Likely to be the world's largest building by footprint, this battery plant, in the desert of northern Nevada, will by 2020 be producing more lithium-ion cells than the world's entire production in 2013. Keeping the battery production in-house gives Tesla cost savings, and it also means the company can keep developing the chemistry and production methods to drive the cost down, helping the Model 3 meet its ambitious price target.

But Tesla has another mission, evidenced by its Powerwall. This wall-mounted box contains a 6.5kWh Tesla motor, plus electronics enabling it to store power from you solar or wind installation, then feed power into your house when they're not generating. Larger systems are available for industrial applications, both as back-up supply and for this increasingly relevant grid smoothing role.



reduction unit. But it means the powertrain has very few moving parts – the motor after all has just one rotating assembly – and the car accelerates with uncanny smoothness because there are no gearchanges. Given the claimed acceleration, it's likely the Model 3 will have a motor power of around 220-240kW (295-322bhp).

ABOVE: **Brilliantly, the Gigafactory is located on Electric Avenue, near the town of Sparks, Nevada. A coincidence? Unlikely**

SUPERCHARGING

Most Model 3 owners will recharge at home, as well as using existing medium-speed public chargers. But they will be able to use the growing network of Tesla-only Superchargers, mostly sited along motorway corridors. They jolt the car with 80 per cent charge in just 30 minutes or so, making long journeys realistic. And, extraordinarily, they're currently free to use for the lifetime of the car.

PRICE

It's only for the US that Tesla has revealed a starting price, at $35,000. The bigger Model S saloon has a baseline price in the US of $71,500, and in the UK it's £63,235, although you can subtract a £4,500 government grant for zero-emission vehicles. Apply the same ratio to the Model 3 and you'd have a figure just less than £31,000, again minus the grant if that remains in place when the car arrives. It will be cheaper to run than an ordinary car, too. At 35mpg and 12,000 miles a year, your current car might cost nearly £2,000 a year in fuel. The Tesla would cost about one fifth of that in electricity.

A RUNAWAY SUCCESS, SO FAR

Tesla's electric cars so far have been utterly unique: stylish, fast, long-range. But there's also been a compelling narrative: a bunch of shiny new-economy visionaries out-running the staid old car companies from a standing start. Tesla is a cult as well as a car company; the Model 3 its play for the mass market. And the world has gone mad for it. Deliveries aren't scheduled to begin until the end of next year, but you can put down £1,000 in the UK to reserve a place in the queue. In the first week the list opened, an astounding 325,000 people did so. So now it's about execution. Tesla must hone the car to production-ready state, greatly step up its car assembly capacity, bring the Gigafactory up to speed, and get reliable cars out of the gate. It's vastly ambitious. But Tesla is used to confounding sceptics and delivering on its vast ambitions.

PHOTOS: TESLA

HYBRIDS, ELECTRICS AND FCVs A BUYER'S GUIDE

While the majority of cars still rely solely on a petrol or diesel engine, there's an increasing number that don't. Most carmakers offer some sort of hybrid or electric alternative, often by converting existing models to handle new drivetrains. In some cases they look identical to their combustion-engine siblings, so you'd have to rummage under the bonnet to know for sure. With that in mind, here's a guide to every hybrid, plug-in hybrid, electric and fuel cell car on sale in the UK today

Words: **Tom Harrison**

PHOTOS: MANUFACTURERS

REGULAR HYBRIDS

Cars with a petrol or diesel engine working with or alongside a battery-powered electric motor. See below for the two types

BMW ActiveHybrid 5 **£47,890**

FORD Mondeo HEV **£26,695**

INFINITI Q50 Hybrid **£41,070**

CITROEN DS5 Hybrid4 **£33,080**

LEXUS RX450h **£46,995**

INFINITI Q70 Hybrid **£43,600**

TOYOTA Prius+ **£26,995**

TOYOTA Auris Touring Sports Hybrid **£21,145**

LEXUS CT200h **£21,245**

LEXUS IS300h **£28,995**

TOYOTA Prius **£21,995**

LEXUS RC300h **£34,995**

TOYOTA Yaris Hybrid **£16,495**

LEXUS NX300h **£29,995**

TOYOTA Auris Hybrid **£20,045**

LEXUS LS600h **£99,995**

MERCEDES S400h **£72,900**

LEXUS GS300h **£33,495**

MERCEDES S300h **£74,250**

MERCEDES C300h **£35,440**

TOYOTA RAV4 Hybrid **£26,195**

PEUGEOT 508 RXH Hybrid4 **£36,860**

PEUGEOT 3008 Hybrid4 **£29,950**

LEXUS GS450h **£45,495**

1. Parallel hybrid: Both the combustion engine and electric motor are attached to one transmission, so they can drive the wheels independently or together
2. Series hybrid: Only the electric motor is connected to the wheels. The combustion engine works as a generator to charge the motor's batteries

PLUG-IN HYBRIDS

Hybrid cars whose batteries can also be charged by plugging into the grid. Hence they have a longer pure-electric range than regular hybrids

BMW
330e PHEV
£33,935

BMW
i8
£104,540

AUDI
A3 Sportback e-tron
£35,690

BMW
X5 xDrive40e
£52,105

BMW
i3 REX
£34,130

MERCEDES
S400 E L
£90,165

AUDI
Q7 e-tron
£64,950

BMW
i3 REX 94AH
£34,480

MERCEDES
C350 e
£38,900

BMW
225xe Active Tourer
£32,655

TOYOTA
Prius Plug-In Hybrid
£28,395

MERCEDES
GLE 500 e
£64,995

MITSUBISHI
Outlander PHEV
£34,249

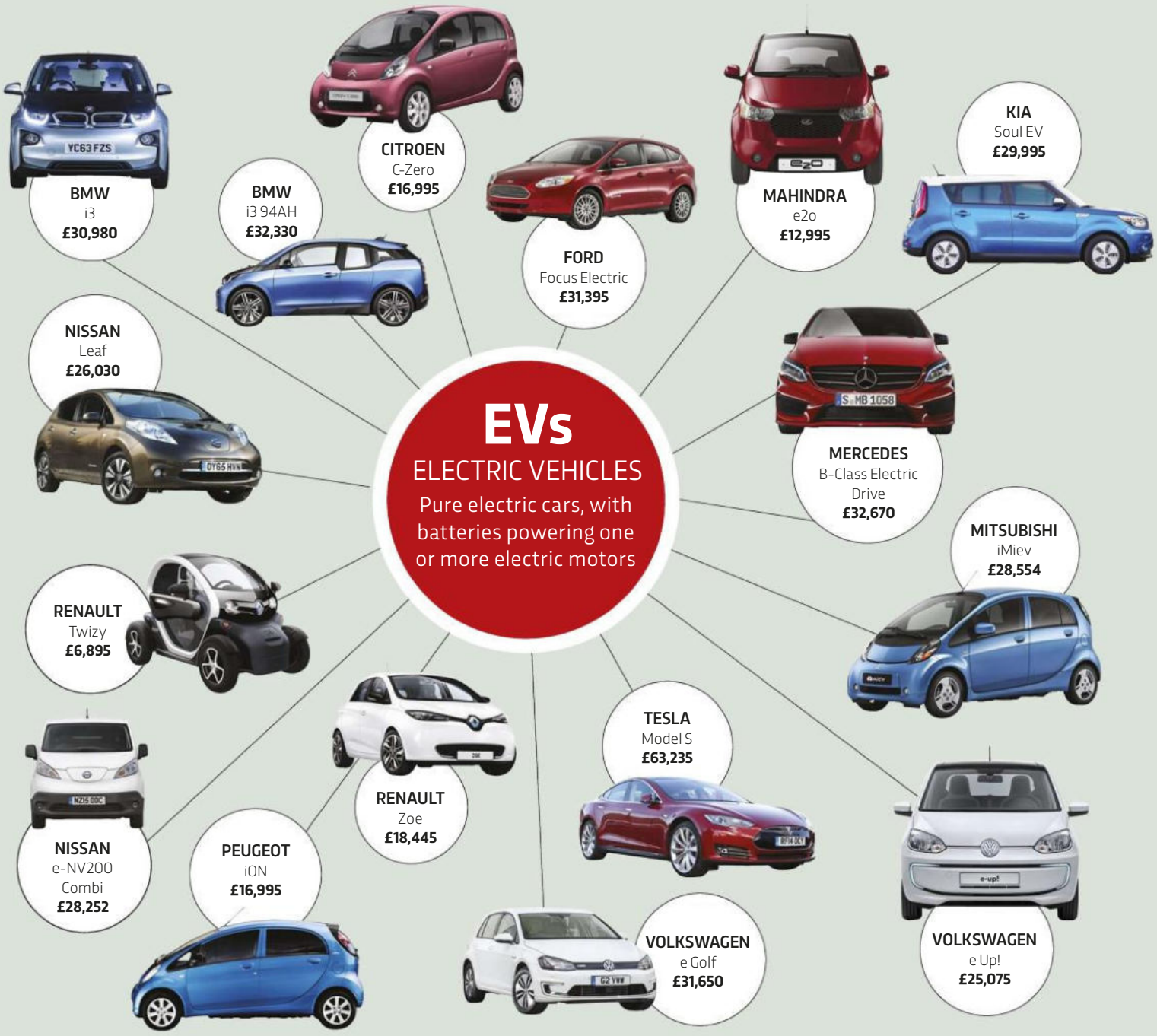
VOLKSWAGEN
Golf GTE
£33,995

VOLVO
V60 Plug-In Hybrid
£64,950

VOLVO
XC90 T8
£60,455

PORSCHE
Cayenne Hybrid
£64,512

PORSCHE
Panamera Hybrid
£82,439


EVs
ELECTRIC VEHICLES
Pure electric cars, with batteries powering one or more electric motors
BMW
i3
£30,980
CITROEN
C-Zero
£16,995
BMW
i3 94AH
£32,330
FORD
Focus Electric
£31,395
MAHINDRA
e2o
£12,995
KIA
Soul EV
£29,995
NISSAN
Leaf
£26,030
MERCEDES
B-Class Electric Drive
£32,670
MITSUBISHI
iMiev
£28,554
RENAULT
Twizy
£6,895
TESLA
Model S
£63,235
RENAULT
Zoe
£18,445
NISSAN
e-NV200 Combi
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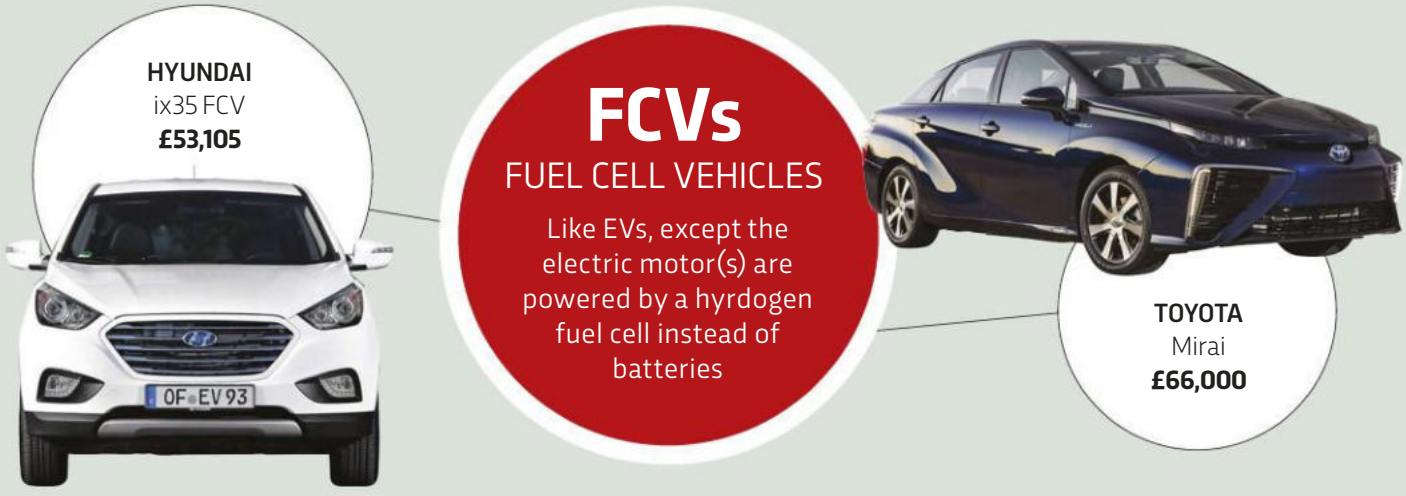
PEUGEOT
iON
£16,995
VOLKSWAGEN
e Golf
£31,650
VOLKSWAGEN
e Up!
£25,075


FCVs
FUEL CELL VEHICLES
Like EVs, except the electric motor(s) are powered by a hyrdogen fuel cell instead of batteries
HYUNDAI
ix35 FCV
£53,105
TOYOTA
Mirai
£66,000

WHAT'S HAPPENING WITH HYBRIDS?

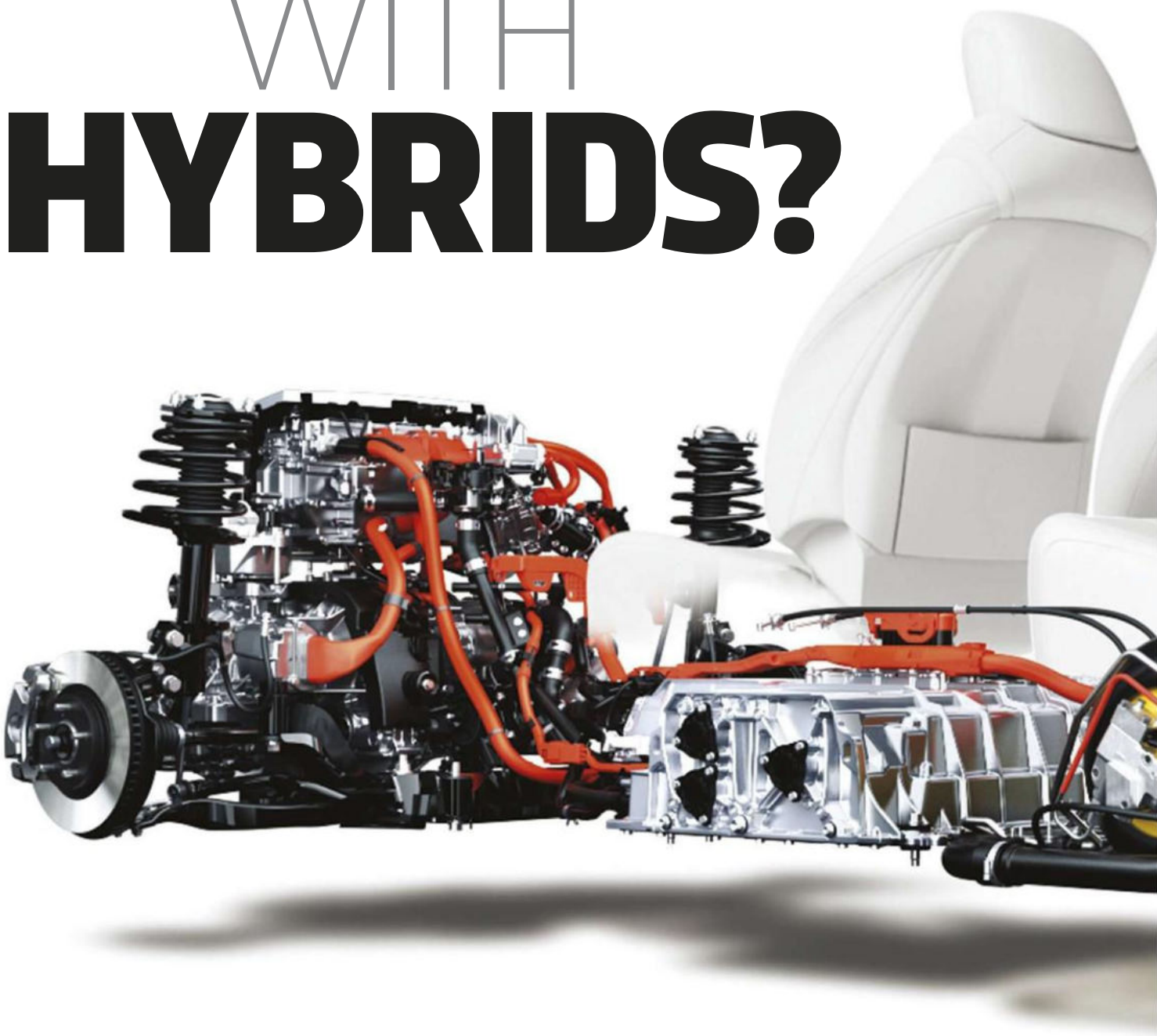
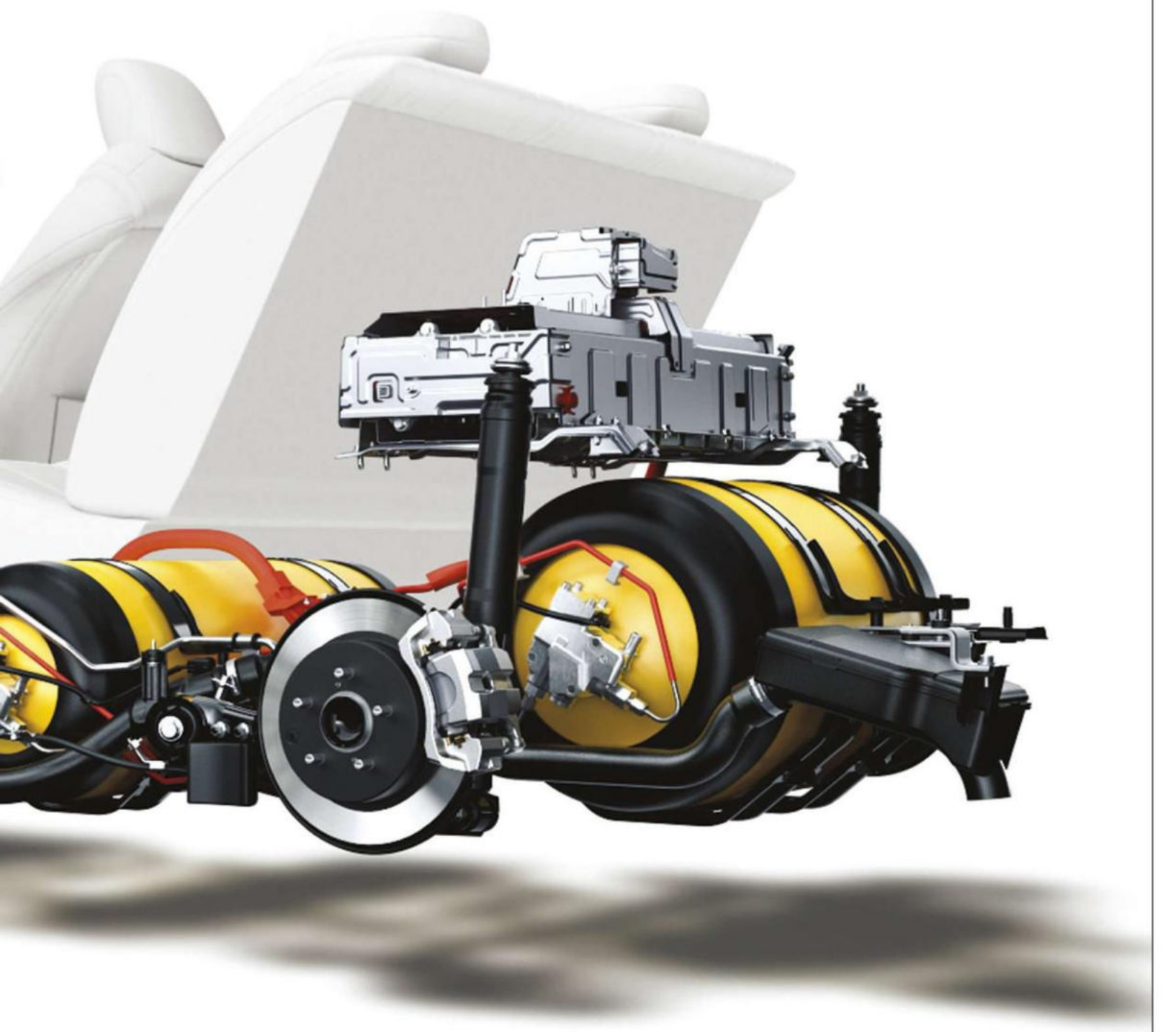


PHOTO: TOYOTA

Once upon a time, buying a hybrid meant buying a Prius. But that was nearly 20 years ago, when they were still the preserve of environmentalists and Hollywood stars. Today, hybrids are for everyone, and they come in all shapes and sizes, some of which you might find surprising...

Words: **Paul Horrell**



The world's most famous hybrid, the Toyota Prius, entered its fourth generation this year, and quietly hums toward five million copies sold since the first one was launched in 1997. No surprise that people think the Prius is the only hybrid. It isn't, and not only do many car makers make hybrids, they use many radically different types.

But they all share a basic principle: the power of the engine is supplemented by a buffering battery and electric motor/generator. When the car is slowing down, kinetic energy can be harvested by the electrical system into the battery rather than uselessly burning off as heat in the brakes – this is what we call regeneration. Then, when the car is moving slowly or cruising on a very light accelerator, the buffer battery feeds the electric motor and the engine can be switched off altogether. That saves fuel. Also, when the engine is at full power, the electric motor gives it a helping hand, so the engine can be smaller than in a conventional car of similar performance. Again, good for fuel consumption. Finally, conventional petrol cars aren't very efficient when going gently at part-throttle. The hybrid system increases the load by recharging the battery, allowing the engine to be shut down for a while later. This means the transmission can be programmed to hold the engine in its most efficient speed/load range or else shut it down, and the engine can be re-designed to work well at that regime. More efficiency gains result.

The energy storage medium doesn't necessarily have to be a battery. Racing cars have experimented with flywheels and big capacitors. Both allow for very rapid input and output of energy – which, in other words, means extra power.

"It's like when your doctor asks you how much you drink each week, and you tell him about the beer but not the whisky"

But by far the most common type is the petrol-engined hybrid. Petrol engines are the cheapest option, especially as the hybrid's electric motor can in effect do the job of a turbocharger. In Europe hybrids haven't taken such a hold because the cheapest and most common fuel-saving option is a non-hybrid diesel engine. But in North America, Japan and China, diesels are very rare, partly because of (recently highlighted) concerns over diesels' NOx emissions, and partly because the necessary low-sulphur diesel fuel isn't always available. Petrol hybrids are very peaceful in town, because the engine is quieter than a diesel, and the electric motor quieter still.

Of course, hybrids have their drawbacks. They're complicated, costly and heavy, thanks to the need for two power units (engine and motor) and two energy stores (petrol tank and battery). Those duplicated systems can be smaller than if they were doing the job alone, but not a lot cheaper.

Also, hybrids open up their biggest advantage in urban and suburban driving where the energy recuperation and engine downsizing do their bit. At a steady-speed cruise on the motorway, the battery buffer isn't much use – a diesel engine tends to do better.

There has been controversy about the extra CO2 load of manufacturing hybrids' batteries. But since most cars produce 85 per cent of their lifetime CO2 in driving, and only about 15 per cent during manufacture, the improvement in fuel economy easily outweighs any small extra manufacturing load.

Having developed the engine and hybrid system, further fuel savings are comparatively easy. Just make the battery bigger, and in most cases the electric motor too, and allow it to be hooked up to the mains. You've got a plug-in hybrid. Most of them can do 20-40 miles using the electric motor. The engine kicks in when the battery is nearly flat and they revert to regular hybrid operation. They appear to be fantastically economical (and hence low in CO2 emissions) in official fuel tests because they can run most of the cycle engine-off, and the depleting electrical energy from the battery isn't counted. It's like when your doctor asks you how much you drink each week, and you tell him about the beer but don't mention the whisky. Even so, running on UK electricity can be a low-CO2 option.

There's another kind of mains-capable hybrid, known as the extended-range electric vehicle, or series hybrid. Here the engine doesn't power the wheels directly – instead it serves as a generator to top up the battery (while an electric motor drives the wheels).

Most dedicated hybrid cars tend to use all available factors to improve economy – low-drag shapes, low-resistance tyres, lightweight materials. Whereas hybridised versions of regular cars have fewer of those tweaks, so they do less well on fuel economy. Taking a fundamentally thirsty vehicle such as a large SUV and then installing a hybrid powertrain might seem a contradiction – like butter on celery. But these big vehicles have most space to package the hybrid components, and the additional cost is small compared with the already high overall price. Finally these are the cars that stand to gain most for saving fuel.

The Prius isn't just about an efficient drivetrain – even the windscreen is made from specially insulated glass

TOYOTA PRIUS

122bhp, 94.2mpg, 70g/km CO2

From £23,295

The Prius was launched in 1997. Since then, over ***5 million have been sold around the world***

The original, relentlessly honed over the years for efficiency. Toyota's hybrid system is quite hard to visualise, but here goes.

The engine, drive motor and a separate generator are mounted in a planetary gearset. The generator is on the sun wheel, the engine drives the planet cage and the drive motor is the outer annulus. As the electronics vary the torque and speed of the motor and the inverse torque of the generator, the effective gearing of the engine changes, and the with it the split of its output between generator and motor. Did we mention it's hard to imagine? The result is probably the most efficient hybrid system out there, but its performance seems strange, as the engine speed is unrelated to road speed.

The Prius, like many hybrids, uses an Atkinson Cycle petrol engine. The inlet valve stays open after the piston starts rising. This allows air back out of the engine. Afterward, when the spark fires, the expansion stroke is effectively longer than the intake stroke, and eking out all the expansion energy extracts more energy from the fuel. The Prius engine converts 40 per cent of the energy of the fuel into useful work, which might not sound much but is actually a record high. The disadvantage of the Atkinson cycle is lower power for the size of engine, here a 1.8-litre petrol. But the added electric power makes up for it: 0-62mph acceleration is a not too sluggish 10.6 seconds.

Fuel economy on the official EU cycle is an amazing 94.2mpg, for a CO2 rating of just 70g/km. In the real world, its economy isn't hurt too much by congestion, but it suffers greatly with hard acceleration and braking and sustained high speed. That's the same for any engine, though. If you want saintly numbers, you know how you have to behave.

Like the previous Prius, the new one will shortly be available as a plug-in hybrid, called Prime. The Prime has a bigger battery at 8.8kWh, chargeable in two hours from a 240V socket for about 22 miles of electric range. To improve electric-only acceleration over the regular Prius's electric mode, the generator switches into a motor.

TOYOTA MIRAI

151bhp, 79mpg (equivalent), 0g/km CO2

£66,000

The Mirai is a hybrid with no engine. Instead, it gets a hydrogen fuel cell – the first one on sale in the UK. Hydrogen and oxygen are pumped into either side of the membranes of the fuel cell, and a catalyst separates the electron from the hydrogen proton. This travels around an electrical circuit back to the oxygen side, where it meets the proton, which is tiny enough to have popped through the membrane. The electrons, protons and oxygen combine to produce water, the only emission. The electricity powers the wheel motor, but a buffer battery enables hybrid tricks: more peak power from the motor, and regeneration for increased efficiency.

The Mirai is Europe's first properly buyable fuel cell car

PHOTOS: MANUFACTURERS

HYUNDAI IONIQ

104bhp, 79mpg, 81g/km CO2
From £18,000 (estimated)

The new Ioniq will be sold as a hybrid, a plug-in hybrid, and then a full-electric version. Unlike the Prius with its continuously variable, power-split transmission, the Ioniq is a parallel hybrid. The engine, the motor, or both, can drive the wheels, and both of them do so through the six-speed double-clutch transmission. The electric motor is sandwiched between the engine and transmission. A clutch separates the combustion engine and allows it to be switched off when the electric motor can do the job. CO2 emissions on the official EU cycle are 79g/km. The plug-in version gets a more powerful motor and bigger battery.

CHEVROLET VOLT

146bhp, 106mpg (equivalent), N/A CO2
£TBC (US only)

The Volt has done fairly well in the USA, but the version badged Vauxhall Ampera flopped here so the Volt's second generation won't cross the Atlantic. Shame, as it's a good car. This is an extended-range electric vehicle, or in some lexicons a series hybrid. It will go for 50-odd miles in pure electric mode, and then the 1.5-litre petrol engine arrives to charge the batteries. Performance doesn't change whether or not the engine is on, whereas on other PHEVs the engine chimes up when you floor the accelerator. The Volt's engine is not connected to the wheels. At least, very seldom, except for certain high-speed cruising.

To eke out maximum efficiency, there are actually two electric motors which do their best work at different speeds, and are coupled together by different gear ratios at various points in the speed/load map.

Chevrolet's idea with the Volt is to have a car whose electric range covers the commute of most Americans, a nation that commutes further than we do.

That way, with nightly home charging, there'll be no petrol used at all. Like any purpose-designed eco-car, the Volt's shape is very much beholden to the wind tunnel, but the second generation is far more conventionally attractive than the first.

A sensible car with ridiculous doors

Supercar Corner
Who says hybrids are boring?

FERRARI LAFERRARI

950bhp, N/A mpg, 330g/km CO2
£1,150,000

Hybrid power increases efficiency. Efficiency can be realised as extra economy or extra power. Guess which Ferrari chose for its £1.15 million range-topper? The LaFerrari has an almighty V12 combustion engine that, on its own, produces an extremely healthy 790bhp at a screaming 9000rpm. To that is coupled a motor-generator unit that can add, during times of peak acceleration, another 160bhp. That's 950bhp in all. The motor harvests regeneration in times when you don't have the road or track space to use the full beans. But thanks to Ferrari's expertise in suspension design, electronic stability controls and aerodynamics, you can use more of the astounding capability than you might expect. If you can afford one, that is.

PHOTOS: MANUFACTURERS

BMW i8

357bhp, 134.5mpg, 49g/km CO2
From £104,540

The i8 is a drop-dead looker, and a scintillating-driving 4WD sports car. It's also a fuel-sipping plug-in hybrid. In a mid-mounted position behind the cabin is a 1.5-litre three-cylinder petrol engine, highly turbocharged for 231bhp. That's hooked to a small motor-generator, and then to a six-speed transmission driving the rear wheels. But the front wheels have their own 131bhp electric motor. A battery sits in the spine of the carbonfibre body.

In Sports Hybrid mode, the petrol-driven rear wheels and electric-driven front wheels get it from 0-62mph in 4.4 seconds. The complex electronics manage the split of effort across the two power sources to give it a helpful torque split for fast cornering. Regeneration happens when slowing down, or indeed when spare engine power pushes against the front wheels. At the other extreme of its astonishing repertoire is Electric Mode. Starting with a fully charged battery from the mains, it will manage about 15 gentle miles before the engine kicks in. For max economy, the body is light (thanks to carbon fibre) and low and very aerodynamically slippery. The i8 even uses 'Gorilla Glass' for the side windows, the same as used for phone screens, because it's thin and light. The tyres are surprisingly thin, helping aerodynamics, but four-wheel-drive compensates. The powertrain all seems very exotic, but actually BMW is being canny in spreading out the technology across its model range – by running it back-to-front. See the new 4WD, PHEV version of its 2-series Active Tourer people carrier, called the 225xe. The three-cylinder engine is moved to the front and drives those wheels, while the main electric motor is at the back. Again it allows electric drive or hybrid. The same system will also be introduced soon on two of the firm's SUVs, where the 4WD aspect will be a big draw.

WHAT'S THE REAL-WORLD RANGE OF A NISSAN LEAF?

Perhaps the single-biggest issue when faced with an all-electric car is how far it will actually go before you must seek a plug. To find out, we got behind the wheel of a Nissan Leaf, and set off

Words: **Stephen Dobie**

There are numerous all-electric cars on sale, but the first to make them a real, everyday proposition – and now the best-selling of the lot – is the Nissan Leaf. Buy it in its most efficient, 30kWh form, and Nissan says it has a range of 155 miles.

ABOVE: **How do you drive yours? Killing the heater boosts range, but you'll need a cardie**

Keen to see how realistic that figure is, *BBC Focus* spent a week commuting through London in one to see what real-world use does to Nissan's claims. In the interests of reflecting how people actually use their cars, we ignored the drivetrain's 'Eco' mode (it limits the instant torque that makes EVs genuinely quick off the line) and used the heated seats and climate control with abandon. If you're wearing extra clothes just to skimp on using the heating, you might as well save more money yet and just get the bus.

We commuted across the Capital for four days, and the battery was asking for a refill after we'd gone just 75 miles, with 13 more miles remaining on its energy gauge. So let's be generous and say a 90-mile range all in, or 60 per cent of Nissan's claim. Our average speed over those 75 miles was 9mph. In

ABOVE: **Pre-heating the cabin while charging is a good way to boost range**

congested cities an EV works well; outside of them, you'll be charging it more and probably fretting about your remaining miles more frequently. A small petrol engine or a hybrid remains a better bet if you frequently go long distances.

But there's a lot to be said about the relaxation an EV brings to the job. A silent drivetrain, simple, gearless operation and the light work it makes of nipping into gaps really do make the Leaf a very pleasant companion. Traffic is notably less stressful, and of course, it has zero emissions at the tailpipe. Besides, with the average hatchback buyer travelling just 30 miles a day, an overall range of 90 miles – below the official claim or not – is plenty enough.

PHOTOS: NISSAN

STATS

RANGE

124 miles (24kWh)
155 miles (30kWh)
Both figures are manufacturer's official claims

PRICE

£21,530* (24kWh)
£25,230* (30kWh)
Road tax: free
Running costs: 2p per mile approx
*Minus govt grant of £4,500

PERFORMANCE

Power: 108bhp
Torque: 187lb ft
0-62mph: 11.5secs
Top speed: 89mph

CHARGING

10,000 public charging points in the UK, plus another 200 Nissan Rapid Chargers.

SALES

200,000-plus (worldwide), 12,000-plus in the UK, where the Leaf accounts for half of all pure EVs sold and a fifth of all plug-in cars.

POWER TO T

A Brief History of Propulsion

3500BC

HORSES
We've had 130 years of history with the motor car, but more than 5,000 years with the horse since it was first domesticated in the area known today as southern Russia and Kazakhstan. Over the years it's pulled chariots, carts and carriages. Incidentally, most carriages would have a length of wood across the front, to shield the driver from dirt 'dashed up' by hooves. Hence the 'dashboard' we still use in cars today.

1770

STEAM
Steam has been used in industry forever. It's powered mills, mine pumps and all sorts. But nobody managed to use it for transport until Nicolas-Joseph Cugnot, a French Army Captain, invented his Fardier à Vapeur in 1770. French for 'steam dray', it was a clunky gun carriage for the battlefield, but it's also generally agreed to be the world's first self-propelled mechanical vehicle.

1838

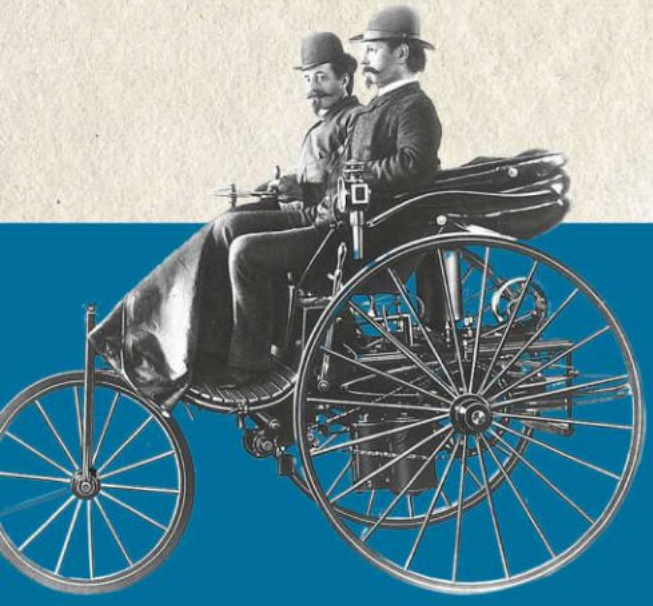
FUEL CELL
It's easy to think of the hydrogen fuel cell as a modern design, but actually it was invented by German-Swiss chemist Christian Friedrich Schönbein in 1838. He also coined the term 'ozone'.

1876

INTERNAL COMBUSTION ENGINE
The combustion engine has a long, complicated history, with all sorts of claims and counter-claims by inventors who played a part in its birth. But a big breakthrough came in 1876, when Nikolaus Otto patented the first practical, four-stroke, combustion engine run on gasoline.

PHOTOS: GETTY, ISTOCK, NEWSPRESS

HE PEOPLE



DIESEL ENGINE
In 1893 Rudolph Diesel invented the compression-ignition engine, in which the fuel in the chamber is ignited by the high temperatures generated when gas is compressed, rather than by a spark plug.

1884

ELECTRIC CAR
Believe it or not, electric cars predate the first gasoline-powered vehicles by about 20 years. The first practical electric car was designed in 1884 by Thomas Parker, who also electrified the London Underground.

1886

PATENT MOTOR WAGEN
Famously, Karl Benz's invention is known as the world's first motor car, but really it was the first vehicle propelled by an internal combustion engine – ten years after Otto's breakthrough.

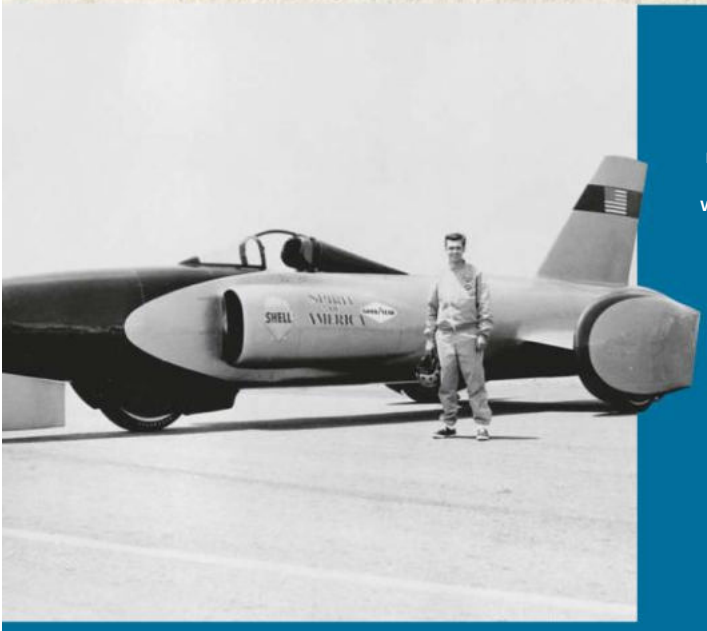
1893

1899

STEAM (AGAIN)
Amazingly, in America for a short period around the turn of the 20st Century, steam cars outsold both petrol and electric vehicles. One of the biggest steam car makers was Stanley, which sold steamers on both sides of the Atlantic until 1924.

1908

MODEL T
The Model T arrived just at the right time: the internal combustion engine had advanced quickly, oil – and therefore petrol – was now cheap and plentiful, and Henry Ford's moving production line lowered the cost of manufacture so that almost everyone could afford a car.



ROCKETS
As the space race reached new heights, it didn't take long for the world of cars to catch on to the idea of rocket power. The Blue Flame wasn't the first car to strap a rocket on its back, but it was probably the most famous, not least because it set a new land speed record of 622mph on the Bonneville Salt Flats in 1970 – a record that stood until 1983.

ELECTRICITY (AGAIN)
After the early success of the electric car, it was pretty much forgotten by the transport world (unless you were a milkman) until Sir Clive Sinclair arrived with his C5, a battery-powered tricycle that could legally be driven on the road by almost anyone – including teenagers without a driving licence. It was arguably the most famous gadget of the 80s, and definitely one of the biggest commercial flops.

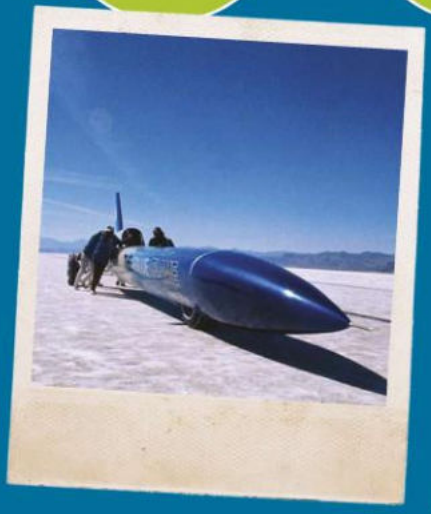
1963

TURBINE CAR
With the jet age came the jet car. Well, sort of. Chrysler's Turbine Car used gas turbines – a type of internal combustion engine – to power a shaft that drove the wheels, rather than propelling the car by thrust in the style of an aeroplane. It was given to members of the public to test, though never caught on.

1963

SPIRIT OF AMERICA
Here's another jet car, and this time it was powered by the thrust of its engine, which just so happened to come from an F-86 Sabre fighter jet. Top speed? Over 400mph. But then again, it was a land speed record machine, and the first of many to bear the *Spirit of America* name.

1970

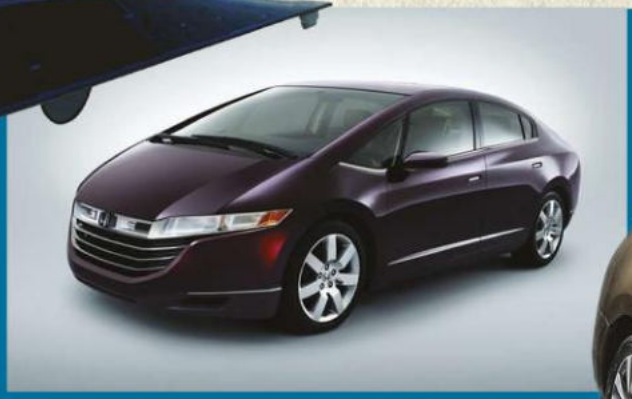


1985

1987

SOLAR
The GM Sunraycer (see what they did there?) was first car to win the World Solar Challenge, a 1,878-mile race across the Australian Outback. Because solar energy generates so little power compared to energy-rich fossil fuels, the key to success is low weight and low drag, hence why it looked like a streamlined cockroach.

PHOTOS: GETTY, ISTOCK, NEWSPRESS



HYBRIDS
The world's most famous Toyota is the one everyone pictures when you say 'hybrid'. It popularised the idea of pairing an electric motor, powered by batteries, with a combustion engine, powered by petrol. It has become globally recognised, though credit should really go to one Dr Ferdinand Porsche, who pioneered the idea of a petrol-electric car nearly 100 years earlier.

NISSAN LEAF
The first mass-produced, pure-electric car, and the one that proved EVs didn't have to look like gadgets – they could, in fact, look like really boring hatchbacks.

1997 2008 2009 2010 2016

FUEL CELL (AGAIN)
Throughout the 1990s and 2000s many companies made prototype hydrogen cars, though Honda was the first to make one commercially available when the FCX Clarity went on sale in 2008.

BLOODHOUND SSC
We've covered a lot on the last few pages, and it all comes together in the British Bloodhound SSC land speed record car. Propulsion comes from two main sources – a jet engine from a Eurofighter Typhoon, plus a rocket fed by both solid and liquid fuel. So it's also a hybrid! What's more, the rocket's fuel pump is actually a Jaguar V8 combustion engine. Top speed? Hopefully 1,000mph or more.

STEAM (AGAIN!)
It might seem like a very Victorian idea, but for some reason steam power just won't go away. This time it provided propulsion for a modern land speed record car with a top speed of 139mph – enough to break a 100-year-old world record of 127mph set by, yep, a Stanley Steamer in 1906.

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FUELLING *THE* FUTURE

For the last century, fossil fuels have dominated our automotive infrastructure. But how much longer can that last? We ask three people at the forefront of the battle of the forecourt, each representing one of the three fuels they believe will power our future cars

Words: **Leon Poultney**

PHOTO: FOSTER AND PARTNERS

"We'll look back at the internal combustion engine and ask 'what was all that about?'"

Dale Vince OBE
Founder of Ecotricity, the UK's largest electric vehicle charging network

You've been instrumental in creating the UK's electric car charging network. Where are we now?
When we began in 2011, it took around eight hours to charge a car but we now have a network of fast chargers in the UK that covers most motorway service stations, as well as key A-roads and some key ports and airports.

There are over 250 Ecotricity charging points in the United Kingdon that can top up a Nissan Leaf in 20 minutes, and we plan to massively expand upon that number in the near future. The electric car is rapidly becoming more popular and we are reacting to this fact.

You've just started charging people to use Ecotricity points. How have they remained free for so long?
Back in the day it was quite easy to keep it free because we were delivering such low volumes of power to very few people. It was actually cheaper to give it away than to charge for it.

We now have something like 40,000 registered users and we're delivering around three million miles of clean driving every month, which is phenomenal. So we have reached a point where we need to start charging a fee to fund the continued expansion and keep ahead of the technology curve.

How realistic is a clean energy future and will it be able to keep up with demand for the electric car?
Absolutely. We've carried out lots of research to ensure that electric cars are sustainable and that includes looking into the amount of lithium in the world to make sure there is enough to create batteries for all cars. There is.

Then we looked at the amount of electricity required if all of the 30 million cars travelling 250 billion miles a year on Britain's roads were to go electric and it was something like a 12 per cent increase in grid delivery. That's really a relatively small figure.

Where do you see the charging network in 10 to 15 years from now?
It will be bigger and more extensive with faster charging points. Ultimately, within a few years we will be able to charge an electric car in five minutes. It will all be very normal and we will look back at the internal combustion engine and ask 'what was all that about?'

There's also a kind of democratisation that comes out of this technology. If you put solar panels on your roof, you can actually make the power to drive your own car and make yourself independent from power companies and that's really quite special.

What are your thoughts on other alternative fuels, such as hydrogen?
I think hydrogen is a mistake because I don't think it stands up to comparison with electric cars. As a fuel, it has a poor energy density, it's very hard to contain and it leaks through metal walls. There's no national infrastructure for hydrogen but we already have a national grid for electricity. Also, hydrogen is a very expensive alternative without the same efficiency as pure electric cars.

PHOTO: ECOTRICITY

"I expect to see petrol and diesel on forecourts for very many years to come"

Matthew Tipper
Vice President of Alternative Energies at Shell

What changes have been made to petrol and diesel fuels in the past few years?
Fuel for transport has been on an upward trajectory in terms of getting progressively cleaner. The major change in the last few years is the amount of biofuels that have been introduced into liquid fuels, reducing our reliance on oil.

What can we expect to see in the next 10-15 years?
In addition to the growth in biofuels we will most certainly see electrification coming to the fore in many guises. The hybridisation of the internal combustion engine will grow in number and there is the potential to move into full electrification via battery-electric vehicles or fuel cell vehicles. In certain economies, probably the affluent parts of the world, we'll see these fleets growing.

Does that worry you as a company that predominantly sells fossil fuels?
No it doesn't worry me at all. We certainly have to adapt in those markets where these vehicles are growing in popularity. We've been working on hydrogen as a product for at least 15 years and we've also been working on charging pure battery electric vehicles for at least four years.

How will forecourts change in the future?
Just as cars are going to change their drivetrains and the fuel mix that supplies them, I expect to see petrol and diesel on forecourts for very many years to come but with increasing levels of biofuel in the blend. In addition to that, we have plans to supply hydrogen on the forecourt, starting in Germany, but soon expanding into the UK.

Will diesel die out anytime soon?
The freight markets, shipping and aviation all use diesel or a diesel variant because it has the highest energy density of all the liquid fuels. I think it will take a long time before we can displace diesel and kerosene from these markets.

It's an open question as to what happens in passenger cars and the light goods market. We may see a trend back to more efficient gasoline engines and hybridisation but it will take many years, if not decades, to displace it.

Has the recent emissions scandal affected your outlook?
I don't think it's affected our long-term outlook. It's been a huge topic of conversation and debate but you have to recognise there's a lot of inertia in the energy system, and it'd take a long time for the vehicle fleet to change. We recognise it's been a significant event but we think the impact on the fuel mix will take hold slowly. Some of the moves away from mineral oil and towards alternatives were happenng long before the VW news.

Why are petrol and diesel still so important?
They are very important to keep roughly 98 or 99 per cent of current vehicles on the road. Mobility is a key enabler to economic growth, and clearly we recognise that we will one day move away from mineral oil. However, it will take time and we can't make that transition without diesel and petrol. In the meantime, there's plenty of room to make the combustion engine ever more efficient.

"We expect 12-15 UK hydrogen stations to be operational by the end of this year"

Michael Dolman
Principal Consultant, Element Energy and the London Hydrogen Network Expansion

Where are we with the hydrogen-refuelling network in this country?
There are currently a lot of different standards surrounding refuelling hydrogen passenger cars, so it is difficult to say, but in terms of fully public stations that meet all of these criteria, there are only a handful right now.

But this is because there are still very few hydrogen fuel cell vehicles. There are around 12-15 stations that are expected to be operational by the end of this year but there's a plan to increase that in the near future.

What do you think the future holds for hydrogen?
We worked very closely with the government and various consortiums on the UK H2 Mobility project, which predicted around 65 stations by 2020, increasing to many hundreds by the mid 2020s. It's all based on the vehicles coming and demand increasing, but the detailed analysis concluded that the UK doesn't actually need that many stations to provide rudimentary coverage across the country.

How can hydrogen fuel benefit our future?
One of the biggest arguments for hydrogen is that you can produce it from many different primary energy sources, including renewables. There are pathways towards producing very low carbon and affordable hydrogen in the future.

Secondly, hydrogen acts as a good way to store energy, which means you can capture excess renewable energy at times of high production and low demand. The result is that you can store energy in hydrogen for long periods.

Finally, there is a GDP argument for producing and delivering hydrogen as a fuel in the UK, rather than outsourcing it.

What are the biggest roadblocks to hydrogen catching on as a fuel?
There is currently work to be done in reducing the cost of the technology, and especially in the transport sector. The hydrogen-fuelled vehicles currently on sale are among the first of their kind, so there is a cost premium at the moment. To get to the scale and subsequent demand, we also need to improve the infrastructure. There are also some small technical issues that need to be ironed out, with regards to hydrogen purity levels and metering the fuel. They are not fundamental roadblocks but rather something the industry needs to address.

How will hydrogen affect other drivetrains and propulsion systems?
A lot of talk around this topic seems to pit one fuel or energy source against the other, but it's not terribly helpful. It's difficult to talk about one solution, as each vehicle size and class has different demands and needs.

There is scope for all of these solutions to work together. A fuel cell vehicle is really just an electric vehicle – they share many of the same components – so a plug-in hydrogen range extender vehicle could benefit from all of the solutions mentioned.

PHOTOS: SHELL, ELEMENT ENERGY

FUTURE ROADS

There are over 245,000 miles of roads in Britain, carrying 35 million cars. So isn't it time they smartened up? Here's how science will change our trusty old tarmac

Words: **Stephen Dobie**

The end of roadworks forever

ROADS WILL BE FLAT-PACKED

Let's start with a simple idea, and one seemingly full of common sense: building roads with Scalextric-style flat-pack panels.

Think about the dreadful tailbacks that ensue when repairs are taking place, or the months of camera-patrolled average speed sections. These could be wiped out if roads were made up of individual panels, with new sections built off site, transported in and snapped into place overnight.

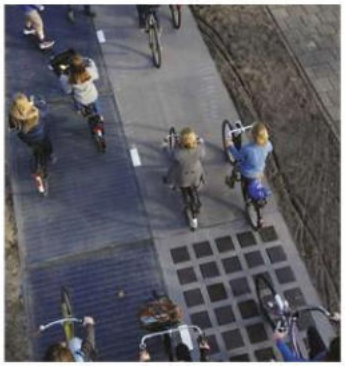
Dutch company VolkerWessels is currently working on hollow, plastic road panels could do just that, and it's something the UK's Transport Research Laboratory (TRL) is monitoring, too.

volkerwessels.com

THEY COULD CREATE THEIR OWN POWER FROM SOLAR RAYS...

What if roads could actually power EVs? This is the idea being pioneered by another Dutch company, SolaRoad. Think about it: our roads have a large surface area directly exposed to the sky. Give those snap-in panels the ability to catch solar rays and you not only have power that can feed the cars they serve, but it can also to give back to the grid. We could also harness the sun's energy to heat water stored beneath the road, creating hydroelectricity.

en.solaroad.nl



...AND THAT MAKES ELECTRIC LORRIES AND BUSES A REALITY

"If you power by road it opens up electrification to trucks and buses as well," says Martin Lamb from the Transport Research Laboratory. The technical requirements and development costs are, naturally, rather big. But if vehicles – particularly freight – could travel via train-like in 'platoons' (see p18), we could control their speed, and therefore the provision of power, because energy use would become more predictable. Just imagine how clear our motorways would be if all the lorries travelled together in one lane.

ROADS WILL ISSUE DIVERSIONS

Vehicle-to-infrastructure wireless networks will feed bespoke info to each car, meaning not everyone has to clog up the same, fuel-sapping route.

THEY COULD CAPTURE CARBON EMITTED BY PASSING VEHICLES

It will be a long time before all of our cars are electric, and roads – or walls that stand beside the road – could help create energy for those that run on traditional fuels, too. Carbon Engineering is a company proposing such technology. Its walls could capture the carbon dioxide emitted by passing vehicles – traditionally a bad thing – and turn it into responsibly-made fuel. "Direct air capture can remove far more CO2 per acre of land footprint than trees and plants," it says.

carbonengineering.com

ROADS WILL BE ABLE TO DE-ICE THEMSELVES

Scientists at the University of Nebraska have invented a road that clears its own ice and snow. The secret? Adding steel shavings and carbon particles to traditional concrete, then passing an electric current through the road surface and/or pavement. The shavings and particles make up about 20 per cent of the mixture – just enough to conduct electricity and therefore produce heat, but not enough to raise the hair of unfortunate pedestrians.

KINETIC ENERGY FROM CARS COULD FEED THE NATIONAL GRID

In 2009 a Sainsbury's car park in Gloucester began capturing energy from shoppers' cars and converting it into electricity to help power the store. But the science dates back much further, to 1880 in fact, when it was discovered that applying mechanical stress to piezoelectric materials led to voltage being produced. It's easier with smaller pressures – so cars, rather than lorries, and it's even been applied to pedestrian footfall. Examples include runners at the Paris marathon, fans walking from tube stations to the 2012 Olympics, and an energy-creating dance floor in a Rotterdam nightclub.

pavegen.com

ROADS WILL EVEN WARN DRIVERS OF BAD WEATHER

French company Eurovia is researching temperature sensitive paint that changes colour when temperatures drop below zero, so you could actually see the cold spots and slow down to avoid skidding on ice.

Meanwhile, if cars are all feeding information to the cloud to keep everyone's sat nav up to date about traffic, their traction control systems could also warn of slippages, long before drivers behind reach the icy tarmac (peer-to-peer comms are already being trialled).

All of which sounds much more helpful than a little snow flake symbol on your dashboard.

eurovia.com

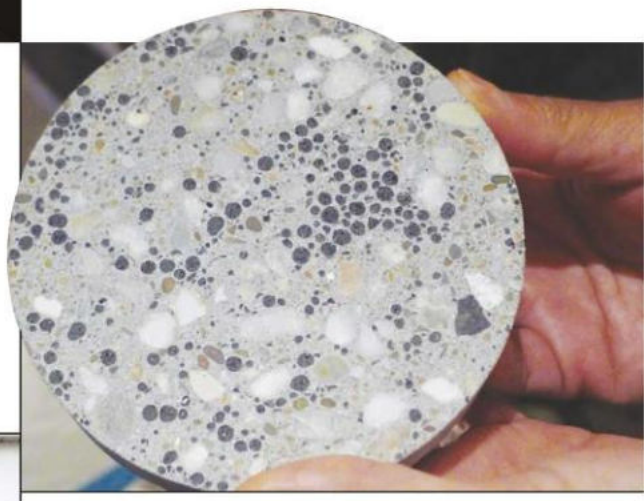
PHOTOS: GETTY, SCOTT SCHRAGE

ROADS WILL BE ABLE TO REPAIR THEMSELVES

Henk Jonkers from Holland's Delft University is currently investigating additives able to reseal the road's surface. The idea is to put powdered bacteria in 'Bio-concrete', which allows natural closing of holes and cracks. Another solution is embedding concrete with steel fibres, which can be heated up to restore suppleness. This would avoid the age-old problem of expansion and contraction that cracks the road surface and leads to all sorts of pesky potholes.

It's all part of the Forever Open Road concept from the Forum of European National Highway Research Laboratories (FERHL), which, alongside Scalextric-inspired construction, wants to ensure our roads are never fully closed for repair.

tudelft.nl



ROADS WILL GIVE YOUR CAR DIRECTIONS

We can already predict with some certainty that one day cars will communicate with each other. But roads will become part of the dialogue too. This means your traditional satellite navigation system will no longer be a lone box suckered onto the screen, it'll be in-car tech fed by this rich seam of information. "Satnav is only part of the entire information system the driver sees in front of them," says TRL's Bob Collis. "All the communication systems we have will come together as we drive."

DISTRACTING SIGNS WILL BE A THING OF THE PAST

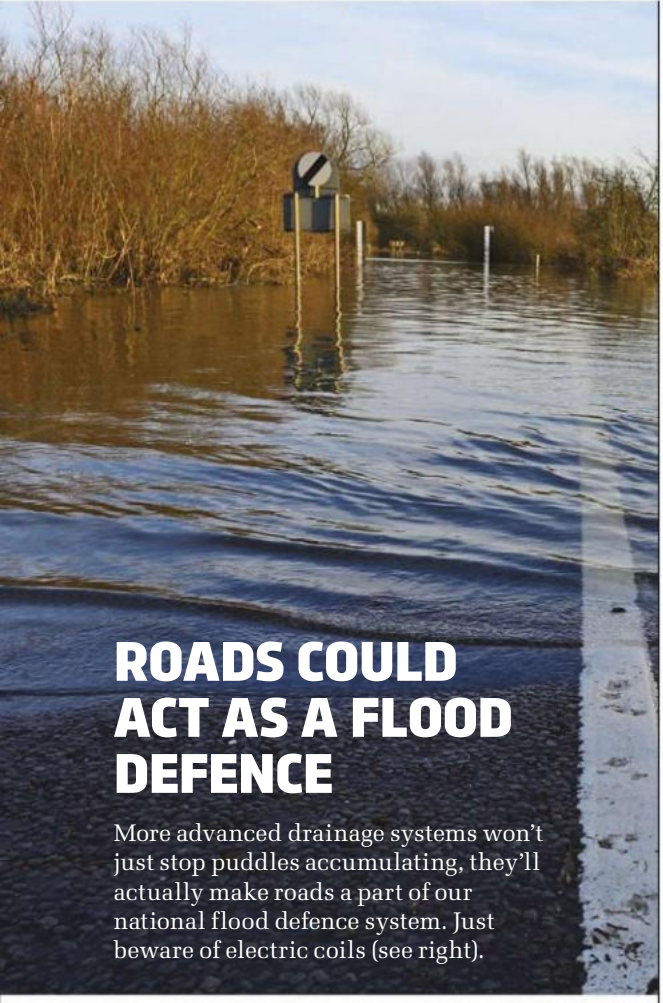
Notice how all of these little features feed into one another? If directions are fed directly to in-car screens, and roads are actively warning us of difficult conditions ahead, then some of our road signs are starting to look a little bit redundant.

De-cluttering busy roadsides would help to keep our eyes on the signs that matter the most, and in turn provide more space for the solar panels and irrigation systems that will make our roads weather-resistant power sources.

TRAFFIC REALLY BAD? THE ROAD WILL TELL YOU TO TAKE THE TRAIN

Combining transport types will become an active part of driving. So long as the governing bodies of road, rail, air and sea all make friends, anyway. The hope is that your customer experience is the same, regardless of which you use.

The benefit? Well, the next time traffic is halting way ahead of you, the road will tell your car to buy a train ticket and direct you to an empty space at the station. No more clogged M25 getting between you and an important meeting.



ROADS COULD ACT AS A FLOOD DEFENCE

More advanced drainage systems won't just stop puddles accumulating, they'll actually make roads a part of our national flood defence system. Just beware of electric coils (see right).

YOU MIGHT GET A MONTHLY UTILITY BILL INSTEAD OF ROAD TAX

Getting energy from the road, then ditching that road for a train when traffic is bad, makes a combined transport bill more sensible than increasingly antiquated road tax.

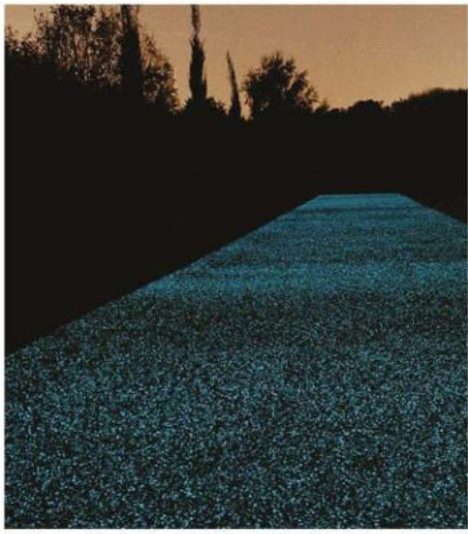
PHOTOS: GETTY, DEPARTMENT OF TRANSPORT

ROADS WILL CHARGE YOUR CAR

Perhaps the Holy Grail for a future electric infrastructure, and the thing that would cure the range anxiety that clouds the idea of buying an electric car for so many people, is the prospect of a road that powers your car. It would contain coils connected to an electric current, while there'd be coils in the bottom of the car which would resonate as it travelled. The resulting magnetic fields would continuously transfer electricity to charge the car's batteries. The UK government is looking long and hard at making this actually happen, and thanks to TRL's work, trials are ongoing as you read this. ***news.stanford.edu***

SMART ROADS COULD MEAN THE END OF STREETLIGHTS

UK company Pro-Teq has developed a product called Starpath, a spray-on substance that captures the sun's light during the day, then emits it at night. It could be applied to the road surface, making it glow-in-the-dark in a variety of colours (red to warn of accident black spots, amber before sharp turns, and so on). But it could also be sprayed onto roadside trees and buildings, so they too become phosphorescent and therefore provide illumination. Losing streetlights also has benefits beyond easing carbon footprints – because the coating is non-reflective and comparatively low intensity, it could massively ease light pollution. ***pro-teqsurfacing.com***



FLASHBACK

ALL HANDS TO THE PUMP

Today's petrol stations aren't really petrol stations – they're just supermarkets with fuel pumps outside. We've come a long way...

Words: **Dan Read**

In the early days of the car, before anyone thought of opening a purpose-built filling station, fuel was generally dispensed in two-gallon jugs by hardware shops, hotels and over-the-counter by pharmacists.

In fact, the world's very first car – a Patent Motorwagen driven by Bertha Benz, whose husband Karl designed it – stopped at a pharmacy during its maiden road trip in 1888. Of course, leaded gasoline wasn't widely used as motor fuel back then, so Bertha filled up with Ligroin, a type of cleaning solvent derived from petroleum.

So perhaps it's not so surprising that a chemist's shop should become the world's first fuel station. But as the car became more popular, so did the idea of filling up at a garage. In the UK, roadside pumps were first installed in 1913, though the first fuel 'station' – made for the sole-purpose of refueling, rather than being a garage – didn't open until 1919. It was built by the Automobile Associated in Aldermaston, Berkshire, and operated by patrolmen in full uniform (see main image). It was a success, and the AA opened another seven stations, selling only British-made benzole fuel – based on coal-tar – rather than the Russian equivalent. Today there are over 8,500 fuel stations in the UK, though the number is declining. In 1994, there were twice as many. If the rise of the electric car continues, they might one day seem like a strange historical footnote.

PHOTO: BRITISH PATHÉ

Dan Read is a motoring writer and a contributing editor to *BBC TopGear* Magazine

Q&A

YOUR QUESTIONS ANSWERED

PHOTO: GETTY

COULD TRAFFIC NOISE BE CONVERTED INTO USEFUL ENERGY?

While it might sound deafening, traffic noise is actually a feeble source of energy. The 100db roar of a passing lorry generates barely a hundredth of a watt of power per square metre. By way of comparison, sunlight is tens of thousands of times more concentrated, producing about 680 watts per square metre. So it's better, then, to harness the kinetic energy produced by traffic as it moves over the road surface, and supplement this with solar panels in the road – together these energy sources could feed into the grid, or even charge electric vehicles as they drive along.

Q&A

IN NUMBERS

20
mb

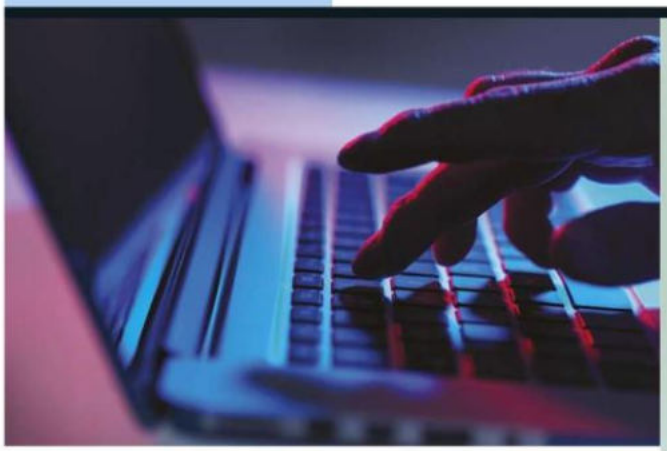
Size of the hard drive in the Compaq LTE 5280 laptop still used to service the 1992 McLaren F1 supercar

14.9
bhp

The generally agreed peak horsepower of an actual horse

Could I use my car wheel as a unicycle?

Funnily enough, yes. In early 2015, Ford filed a patent for a whacky system that would convert one of your car's wheels into a self-balancing unicycle. Firstly, a built-in, automatic jack would lift the car so you could easily remove a wheel, helped by a quick release function. Within the hub of the removed wheel is an electric motor and battery pack, which will most likely be pre-charged by the car's engine. The saddle and handlebar unit – which you store in the boot – would click into place, and, bingo, the end result would resemble the gyroscopic RYNO (pictured above). Whether you're happy to look like a sci-fi circus performer is another matter.

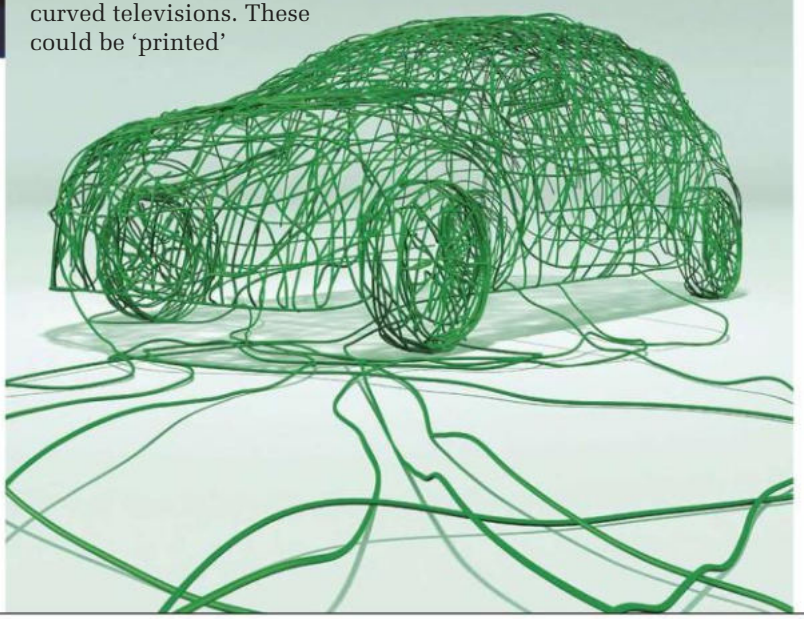


Might my car be hacked?

Yes, especially as they become more connected. In a controlled experiment last year, two hackers successfully disabled a Jeep as it drove along an American highway, prompting Chrysler to recall 1.4 million cars and the FBI to make an official announcement. Their advice? Keep software up-to-date, pay attention to official recalls (especially those offering cybersecurity patches), avoid any unauthorised changes to a vehicle's software and be careful about plugging insecure gadgets into the car, including 'black boxes' for insurance purposes.

Do cars still need wiring looms?

Although they're hidden away behind trim and under carpets, traditional, copper-based wiring looms still take up space and add weight. In future they could be replaced by wafer-thin and bendable printed electronic circuits, currently used in curved televisions. These could be 'printed' into the car's body panels and provide a lightweight, space-saving alternative to traditional wiring for instruments, switches, lighting, heating and screens. The tech is being investigated by JLR in the UK.



PHOTOS: RYNO MOTORS, GETTY

Why do V8s sound good?

A V8 engine has two rows of four cylinders arranged in a V shape, and – in the cross-plane crankshaft type, rather than a flat-plane – these cylinders fire in an irregular pattern across the two rows. During each piston's cycle it produces a pulse of air pressure, which is forced out through the exhausts (they effectively become wind instruments). Each pulse makes a tone, which combined with the other pulses forms a harmonic series. The same thing happens in all engines, but it's the irregular firing sequence that gives a big V8 its distinctive throbbing sound.

Can we make tyres from dandelions?

To reduce dependence on south-east Asian rubber trees, the tyre industry is looking for more sustainable alternatives. Synthetic rubber is one option, although natural sources have far better performance qualities in terms of grip and load-bearing ability. One such source is the Russian dandelion, which is actually indigenous to the high plateau of south-east Kazakhstan, and the bordering areas of China and Kyrgyzstan. This usually pesky weed has a high content of natural latex, which tyre company Continental has converted into a material it calls Taraxagum. From this it made a batch of prototype tyres, which are currently undergoing tests. Early results are "promising", says the company, and the dandelion tyres could enter production within the next five to ten years.

WHAT'S TURBO LAG AND CAN WE CURE IT?

A turbocharger works by forcing exhaust gases back into the combustion chambers (cylinders), therefore increasing power. The problem is that it takes time to build exhaust pressure and to 'spool' a turbo. That's why, when you put your foot down at a low engine speed (rpm) you experience 'lag' before the turbo wakes up. It's especially evident in diesel engines, which rely on compression ignition rather than spark plugs. Various systems exist to overcome this, but Volvo hopes to cure it completely with a system called Powerpulse, featuring a compressor that draws clean air from the airbox and stores it in a tank. When the driver suddenly accelerates, a valve opens, sending high-pressure air from the tank into the exhaust stream, quickly spooling up the turbo and resulting in a pulse of power. Hence the name.

PHOTOS: GETTY, VOLVO, CONTINENTAL

Do we still need car keys?

Not really. In fact, Volvo plans to completely do away with physical keys by 2017, replacing them with an encrypted phone app that will talk to your car via Bluetooth. Jaguar has a similar system that works with an Android Wear watch. This is different to the 'keyless' entry and start systems available on cars now, which still require you to carry a traditional fob, even if you don't actually have to press a button or insert it into a lock or ignition barrel.

What happened to airless tyres?

We've toyed with the idea for decades – they were used on NASA's Lunar Rovers – but it's taken some time for the non-pneumatic tyre to catch on as an everyday proposition in mainstream vehicles. Finally, in the last year or so, Michelin has commenced sales of its airless Tweel, though it's only really designed for use on construction vehicles and agricultural equipment. Replacing air-filled inner tubes with polyurethane spokes has obvious advantages – no more punctures, for a start – though this type of fabrication is more prone to breakage, vibration and heat build-up, which makes it far from ideal for use with high-speed road cars.

Will F1 cars have windscreens?

After the recent, and extremely tragic death of F1 driver Jules Bianchi, it's looking increasingly likely that Formula 1 cars will eventually incorporate some sort of device, other than a helmet, to help protect the driver's head. Ferrari and Mercedes have tested similar 'halo' systems, made up of a sort of hoop around the open cockpit. Red Bull Racing has gone further, by trying out an actual windscreen (pictured above). But the idea of a closed or partially-closed cockpit remains a very controversial idea, with some drivers all for it while others are actively speaking out against the idea.

PHOTOS: VOLVO, GETTY, MICHELIN, GOODYEAR, FORD

Will we reinvent the wheel?

Goodyear thinks it might, with an idea for a completely spherical tyre called the Eagle-360. The benefits are a bigger contact patch with the road, the ability to fling off water with centrifugal force, and being able to roll sideways into tight parking spaces or spin around on the spot. Of course, you would ruin that party trick if the tyres were attached to the car by clunky suspension linkages, which is why the 360s would use magnetic levitation – maglev – to suspend the car over the tyres. They haven't mentioned much about steering, though…

How big is my car's brain?

It actually has many – even basic cars have about 30 microprocessor units, rising to 100 or more in luxury cars, some of which run 100 million lines of code. One of the most obvious, because you can see the results on a screen, is the one powering the digital dashboard. Nvidia's CX (as found in the new Audi TT) is a cockpit computer with roughly the same processing power as a MacBook Air. And that's just one – you also have CPUs looking after automatic wipers, traction control, gearbox, not to mention the engine with its very specific fuel injection timings, air-to-fuel ratio and so on.

IN NUMBERS

5.4 tonnes

of carbon dioxide absorbed by the average hectare of British woodland each year

That's enough to absorb the CO2 produced by driving a VW Golf 2.0 TDI for approximately

31,000 miles

121.4 g/km

Average UK new car CO2 emissions in 2015

What on earth is going on here and are those dummies OK?

Don't worry, they're perfectly fine. In fact, they couldn't be much safer, because those things across their chests aren't just ordinary seatbelts, they're Ford's new inflatable seatbelts. Designed primarily for younger and elderly passengers sitting in the back seats, the airbags are designed to spread crash forces across a greater area of the body – up to five times the area of traditional belts – rather than cushioning you from a blow as a regular airbag might do. Expect to see the belts as an optional extra on the new Ford Explorer in the US, followed by more models worldwide.

Can my car tell if I'm having a heart attack?

Some cars – from Skodas to Mercedes Benzes – already have wellness monitors capable of detecting driver drowsiness, and until 2014 Ford was working on a special seat that contained electro-cardiograph monitors in the backrest, combined with an in-car camera that detected a driver slumping in their seat – if it thought you were in trouble, the car would bring itself to a stop, hopefully not in the fast lane of a busy motorway, and call the emergency services. But the project was abandoned, with Ford saying it would instead explore the potential for wearable devices to inform the car of the driver's state of health.

PHOTOS: NASA, SCIENCE PHOTO LIBRARY, ISTOCK. ILLUSTRATOR: SAM FALCONER

Will my car detect potholes?

Some cars already can. A Land Rover Discovery Sport with MagneRide suspension has sensors that profile the road surface under the wheels and identify potholes, raised manholes and broken drain covers. By monitoring the motion of the vehicle and changes in the height of the suspension, the car is able to continuously adjust the suspension characteristics, giving a more comfortable ride over damaged road surfaces. However, the tech is only reactive, so the next step – which JLR is already developing – is to create a predictive system with road-reading sensors (possibly using the car's stereo cameras), that tells the suspension to prepare for upcoming bumps.

PHOTOS: FORD, JAGUAR LAND ROVER, GETTY, ALAMY

Do we still need windscreen wipers?

We might be living in a world of driverless pods and gesture control, but no matter how much technology is crammed into your car, it still relies on a couple of rubber strips to swish raindrops off the windscreen. Recently though, McLaren – which makes cars for the road and for racing – said it was looking into the possibility of using ultrasound to create tiny vibrations on the screen, which would shake off rain, insects and even specs of mud and dirt. The company says it borrowed the idea from a secret military source, and that a very similar system was used on fighter jets. Unfortunately there's still no sign of a prototype, so for now we'll have to stick with wipers and a generous coating of Rainex.

Will engines run on air?

Air-powered equipment is all around us, from the guns that unfasten your wheel nuts to the pneumatic drills on building sites. So using compressed air to move pistons in an engine isn't such a daft idea – French company MDI has been working on the concept since 1991, and in 2013 it announced it would make the AirPod, a car powered by a compressed air engine. Production plans are still being finalized, but MDI says it will charge between €6,000 and €9,000 for each car, depending on the specification.

HOW TO PRINT A CAR

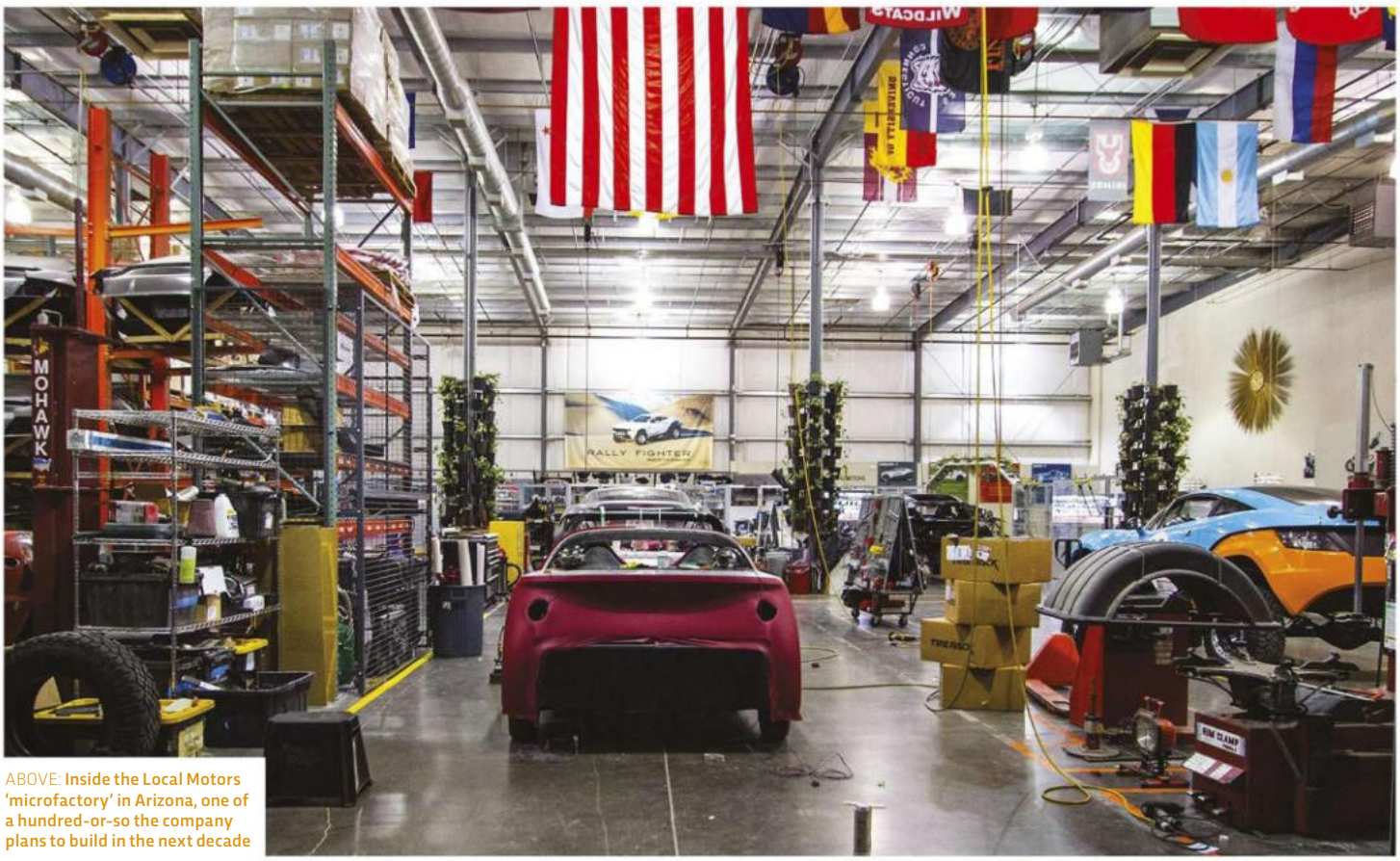
Some say we're on the verge of another industrial revolution, and that 3D printing will be the tipping point. It's even changing how we make our cars

Words: **Jack Rix**

PHOTO: LOCAL MOTORS

The day when you roll out of bed, pull on your 3D printed slippers and eat a 3D printed breakfast, before leaving your 3D printed house and climbing into your 3D printed car is no longer a speck on the horizon, it's speeding right towards us. Once considered the preserve of multi-million pound labs, you can now purchase a 3D printer for your home from under £300, while printing or 'additive manufacturing' on an industrial scale is getting faster and more affordable by the day.

Over the next four years 3D printing is expected to triple in size to a $21bn global industry, with the automotive and consumer electronics industries responsible for a 40 per cent chunk of that. The question is, are we talking about the odd obscure widget under your bonnet, or could we go the whole ▸



ABOVE: **Inside the Local Motors 'microfactory' in Arizona, one of a hundred-or-so the company plans to build in the next decade**

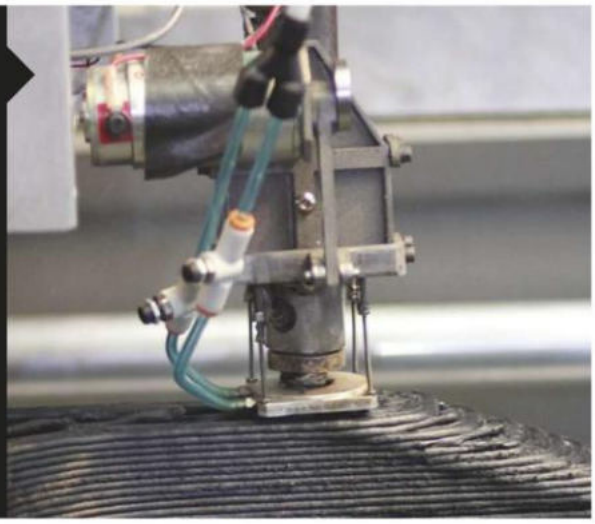
The LM3D Swim is 70 per cent 3D-printed. Yours for $50,000

The 3D-printed wheelarch from the Local Motors Strati

PHOTOS: LOCAL MOTORS

3D PRINTING IN AEROSPACE

The aerospace industry has always resided on the bleeding edge of technology, now 3D printing is on the bleeding edge of aeroplane design. General Electric recently unveiled and began testing the world's largest jet engine; a development of the one currently fitted to the 787 Dreamliner, designed to fit the next-gen Boeing 777X. It features 3D printed fuel nozzles – for the perfect shape and therefore spray pattern – but also 3D printed titanium-edged Ceramic Matrix Composite (CMC) blades that let the engine run hotter, and therefore leaner. Meanwhile, earlier this year NASA announced the successful testing of a 3D printed fuel pump that could well feature in a methane-fuelled Mars lander. So you see, it really is rocket science.



hog and replace the traditional car dealership experience with immersive online configuration before simply pressing print? In all likelihood, it's a bit of both. But before we get into that, let's establish the benefits of 3D printing over traditional manufacturing processes such as injection moulding and CNC milling. Ford, which has five 3D prototyping centres scattered across the world, says the benefits are measured in time, not money. Why? Because speeding up a new car's gestation time and bringing it to market a month early means an extra month of sales, and potentially millions more in profit.

"At the Detroit Motor Show, Local Motors printed an entire car, in front of stunned onlookers, in just 44 hours"

FASTER PROTOTYPING

In the good ol' days, manufacturers would have to send blueprints to a fabrication shop, which might take weeks or even months to send back a part. Only then would they discover that it didn't fit or do the exact job they want it to, so they'd make the changes and the long wait would begin again. Now it's simply a case of 'drawing' the part in CAD software and printing the part on-site in a matter of hours. If it isn't perfect, you simply tweak it on the screen and hit print again.

But that's not all, because with advanced new 3D printing methods being developed all the time, you can even have your part in a wide variety of materials, in unusual and delicate shapes and with complicated internal structures that optimise strength where it's needed, and cut weight where it's not. And imagine this: rather than having to visit a dealer, buy a replacement part and wait for it to be fitted if, say, your wing mirror were damaged, you could simply pay to download the file and print yourself a new part on your Makerbot or Dremel, all from the comfort of your own garage.

One of the most promising of these emerging technologies is called CLIP (continuous liquid interface production), pioneered by Californian company Carbon 3D. Unlike the layered printing processes that are basically 2D printing repeated ad infinitum, woefully slow and produce inherently weak components when stressed in certain directions, CLIP shines UV light through a special filter as a slow-rising platform 'pulls' the object from a polymer reservoir. It's around 25 to 100 times faster than other methods and capable of building mesmerising geometric shapes. In fact, Ford has already begun playing around with one of its pre-release devices.

Where it starts to get really exciting, though, is when you have a company starting from a clean sheet of paper, and daring to imagine that an entire car could be built in a completely different way. A company such as Local Motors – the wonderfully disruptive start-up based in Phoenix, Arizona that's already showed its ability to think outside the box. Its first product, the Rally Fighter, was a car you bought and were invited to build yourself in the company's micro factory.

Its next project is called the LM3D (see images, left) – an electric car made from 75 per cent 3D printed materials. You can order now for around $50,000, with first deliveries due sometime in early 2017. The design was the result of a competition that attracted hundreds of entries, with Kevin Lo's funky open-top four-seater eventually getting the nod, and – vitally – going from computer sketch to reality in a matter of months, not the years that are required for mass-produced cars up to this point. To demonstrate it's not making this stuff up, Local Motors 3D-printed an entire car called the Strati at the 2015 Detroit Motor show, right in front of stunned onlookers, in just 44 hours.

INFINITE UPGRADES

Not content with that, the company has recently announced an idea that lets its customers upgrade their cars during the ownership cycle – and we're not just talking about adding some stripes to the roof, or an over-the-air software upgrade like the one you get in a Tesla Model S. Nope, they're proposing melting down the body and reprinting it as a completely

ABOVE: **The dinky Canadian URBEE (orange) meets the beefy American Blade (silver). Which one's your money on?**

new body shape. "In automotive, for about 100 years, we've been doing things incrementally better on a fundamentally similar platform," says Justin Fishkin, Local Motor's chief strategy officer.

"We need to increase the pace of that development. People might actually want to keep their car longer, or they'll say, 'I want to bring it back and have a better car by the end of the day'."

UNDER THE SKIN

If you can stomach the Robin Reliant jokes, and want something even more radical, then there's a 3D-printed car currently being developed and awaiting funding in Canada, called the URBEE. A three-wheeled, two-seat, aero-obsessed blimp of a car powered by a hybrid powertrain consisting of a lawnmower engine, batteries and an electric motor, it has a target fuel economy of 349mpg – roughly six times more than your average VW Golf diesel. Thing is, like the LM3D, the body and interior can be printed, but the structural components need to be sourced through traditional streams.

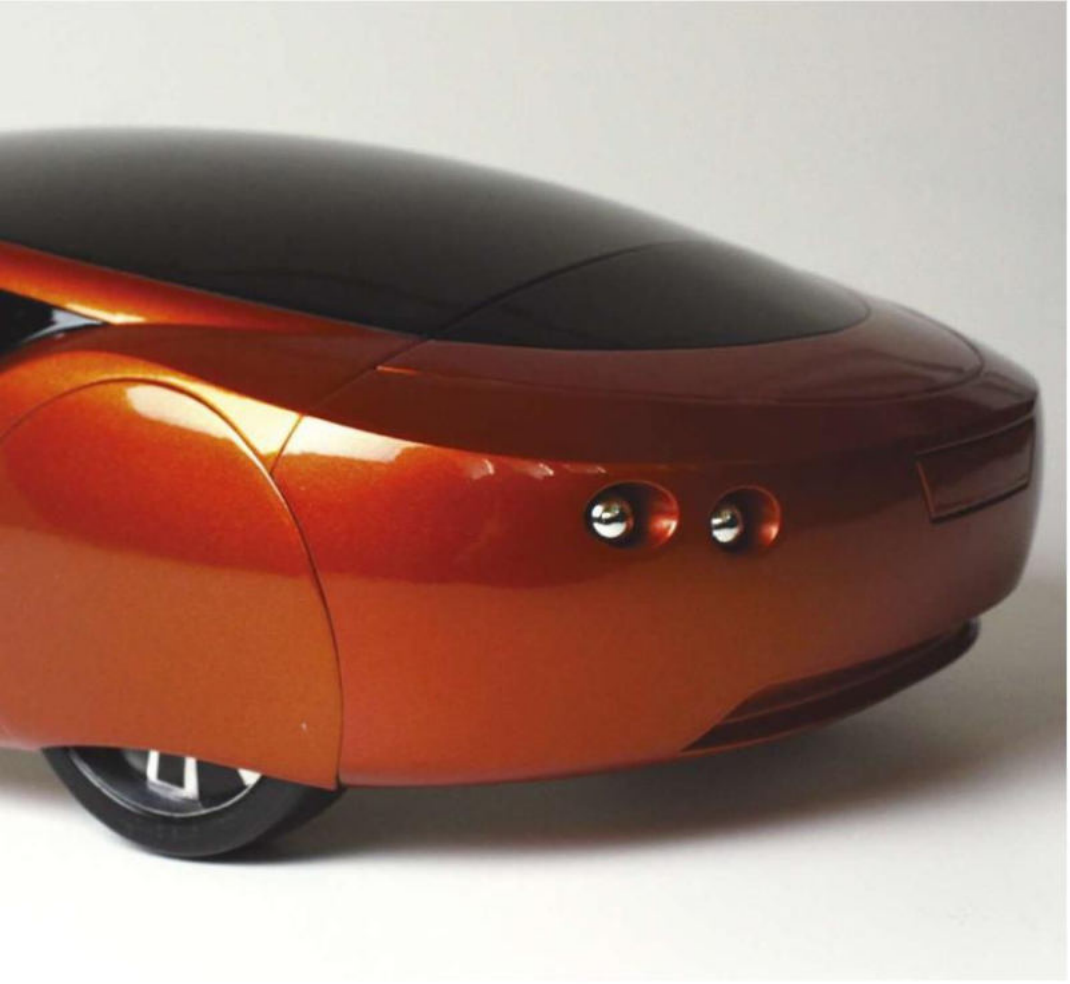
"The Blade's chassis is like the motherboard, you just plug in whatever components you like"

So perhaps both companies should put a call into Kevin Czinger, founder and CEO of an American startup firm called Divergent Microfactories. Why? Because his focus isn't on 3D printing the panels you can see, it's about a new, flexible way of manufacturing the bits you can't. And like any entrepreneur worth his stock, he's showcasing his technology in a car designed to appeal to your inner child.

"I've done wheelies in it. I've lifted the front wheel going up a hill in fourth gear by four or five inches," he says. The car he's talking about is his DM Blade (see picture, above) – the world's very first 3D-printed supercar that he hopes to put into limited production, although that's not the extent of his grand vision.

"The core company aim is to work with OEMs and licence the tech for higher-volume cars," Czinger explains. "But within 18 months we'll make a street-

PHOTOS: DIVERGENT MICROFACTORIES, KOR ECOLOGIC



legal Blade, and sell a small run of the cars."

As you may have guessed from the image (left), not every part of the Blade is 3D-printed. The composite panels are made with fairly traditional methods (although they could be printed in the future when the tech improves, say Czinger), as are perishable components such as brake discs, brake pads and tyres. But it's in the aluminium and carbon-fibre chassis where the magic happens.

Each car is constructed from 70 or so 3D-printed, aluminium alloy nodes, the largest of which takes around four hours to print. Each node is connected to the chassis by simple and relatively cheap carbon fibre rods of varying lengths. "The chassis is like the motherboard, you just plug in whatever components you like," Czinger says. "As a result it's easy to adapt the system for anything from a two-seater to a pick-up truck."

The Blade, as the name suggests, is no commercial vehicle, it's a full-blown supercar stuffed with a tuned version of the Mitsubishi Evo X's 2.0-litre petrol engine. Specifically, it's bored out to 2.4 litres, converted to run on compressed natural gas and, just for good measure, fitted with a huge turbocharger. These modifications take the power output to a faintly absurd 700bhp, while the torque figure tops out around 500lb ft. In order to cope with the forces produced by such heady figures, the gearbox is a Holiger six-speed sequential chosen, say Czinger, for its "raw, racecar feel."

Given the Blade weighs in at 630kg, that power figure starts to look like quite a lot, and explains why 0-60mph is apparently dispatched in 2.2 seconds. In fact, the Blade has nearly twice the power-to-weight ratio of a Bugatti Veyron.

In truth, projects like the Blade and LM3D are really just the icing on an increasingly big cake. The real story here is that manufacturing a car is an extraordinarily energy-intensive process, so any new technology that can reduce costs, minimise weight and speed up development and manufacturing will be leapt upon by an industry constantly sniffing around for ways to improve its bottom line. 3D printing isn't a silver bullet for the car industry, but there's no doubt it's going to play an intrinsic role in your car of the future.

PHOTOS: GETTY, VVZLAD/WIKIPEDIA

THREE 3D PRINTING APPLICATIONS YOU MIGHT NOT EXPECT

FOOD

Special 3D printers, like the 3D Systems ChefJet, can lay sugar into virtually any geometric pattern you like – surpassing the kind of intricate sugar sculptures even the world's most talented pastry chefs can muster. Printers capable of producing more substantial savoury snacks, such as pizzas, are also under development, but with infinite flavour combinations to grapple with, we're a long way from just pressing ctrl+P when the kids get home from school.

HUMAN STEM CELLS

The latest techniques allow scientists to 'print' uniform 3D blocks of stem cells, the embryonic cells that can develop into any type of tissue. The big benefit is it allows new tissue to be grown in a controlled and predictable manner in a lab. The end game? Nobody will need to wait on an organ donor – the doctors will simply grow a new one to order.

A GUN

Designed by gun enthusiast Cody Wilson, the 'Liberator' is entirely 3D printable, except for a firing pin made from a metal nail. When Wilson's company released the plans for the gun online in 2013, they were downloaded 100,000 times before the US Government demanded they were retracted.

ELECTRIC LIGHT ORCHESTRA

Of all the thousands of parts on the new Mercedes E-Class, the 84 tiny LEDs in each headlight could be the most revolutionary. Here's why...

Words: **Tom Harrison**

The first car with full-LED headlights was the Audi R8 in 2008, but LEDs are no longer the preserve of supercars and sumptuous limousines. Nowadays even the humdrum Vauxhall Astra can be specified with them – and we're not talking about those twinkly daytime running lights, either. Nope, these are fully-adaptive setups with many, many LEDs per unit.

First and foremost, LEDs are a kind of semiconductor that light up when a current is passed through them. They are practically maintenance-free, far more efficient than Halogen or Xenon bulbs, and the light they give off is friendlier to the eye because it more closely resembles daylight, therefore reducing driver fatigue. Then you have the increased range on high-beam, plus greater precision.

Take Mercedes, for example. Its new E-Class has 84 LEDs in each headlight (pictured above), up from 24 in the S- and CLS-Class. Think of the headlights as televisions – the more pixels you have, the better the resolution. The LEDs are arranged in a grid pattern, and can be individually controlled, so the light pattern can be altered depending on the conditions. Oncoming vehicles – and those ahead of you – are identified and masked within a fraction of a second and the beam changes shape if you're driving through town, on a motorway, in the countryside (the system is linked to the GPS) or if it's raining. And that's not all. Audi, Volvo, Ford, BMW and others all have systems with similar skills, if not as many LEDs in each headlight.

LEDs are very much today's tech. Next up for headlights are lasers, which are actually already available in the Audi R8 and BMW 7-Series – they work by converting blue lasers into harmless white light, for a brilliantly bright beam, way brighter than LEDs. Then we have OLEDs, which produce a more homogenous kind of light, emitted by ultra-thin semi-conductive layers made from organic materials.

PHOTO: MERCEDES-BENZ/DAIMLER AG

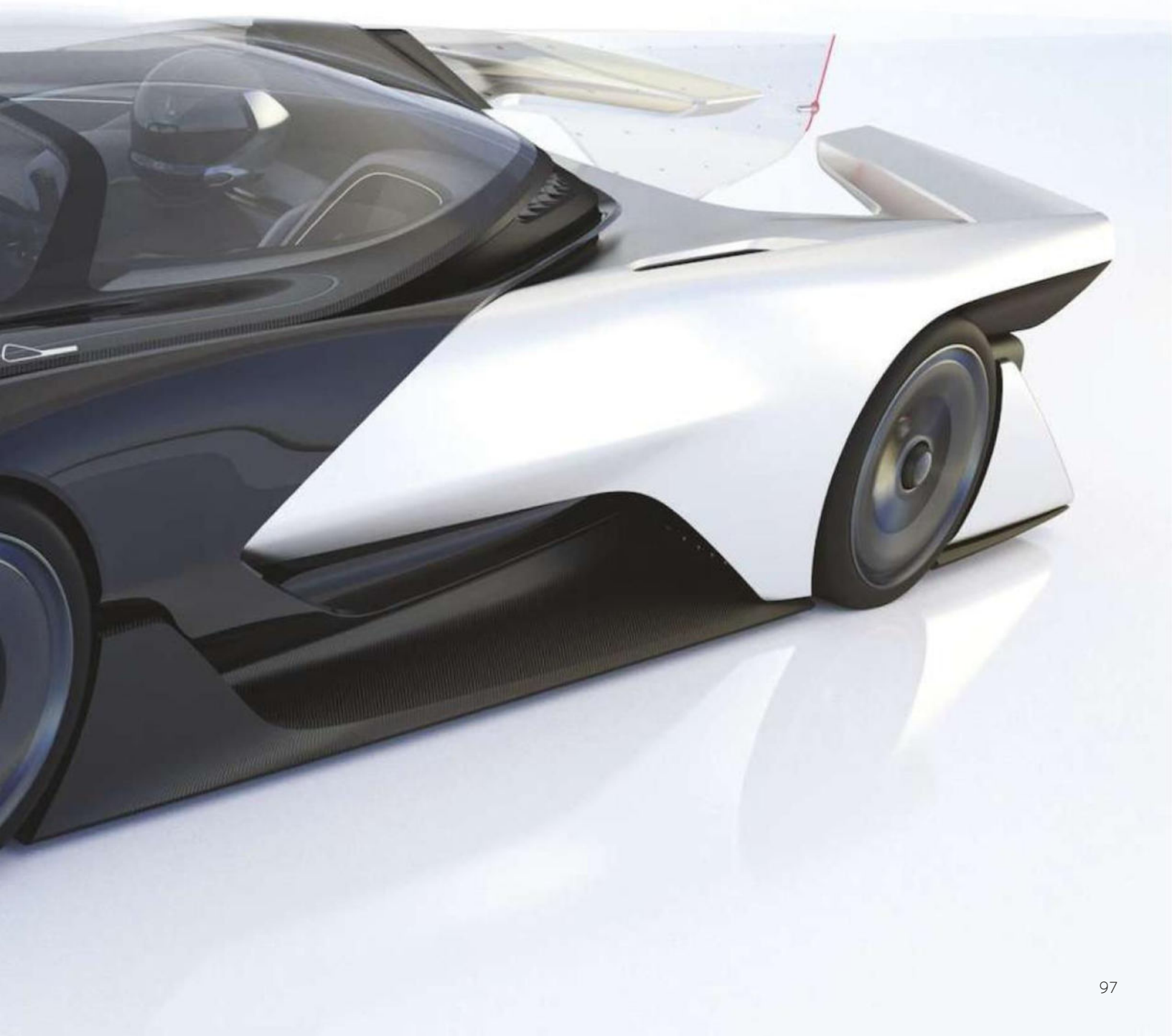

MULTIBEAM LED

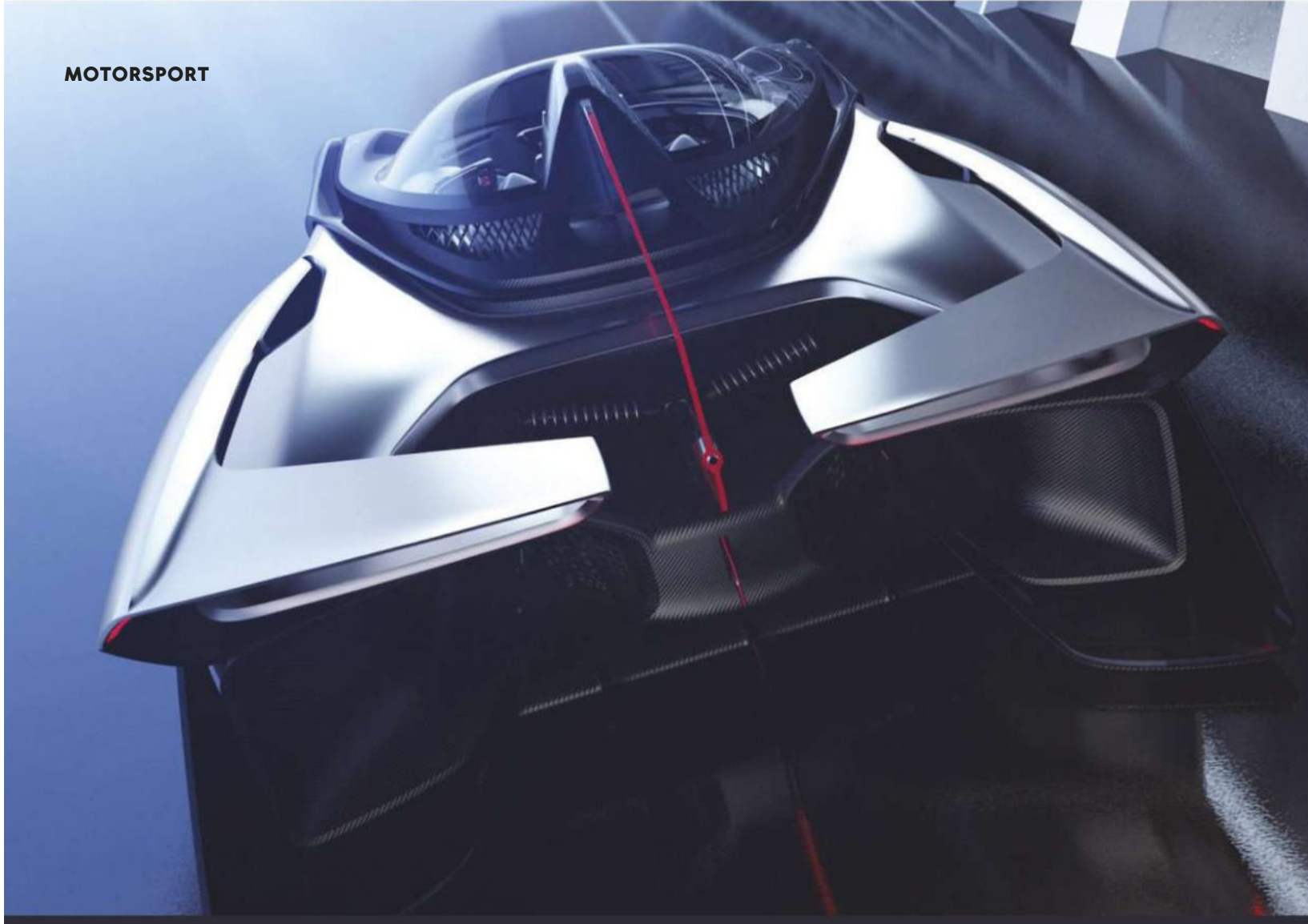
FARADAY UNCAGED

ILLUSTRATION: FARADAY FUTURE

Adaptable chassis tech, smartphone enabled vehicle set-up, zero-gravity seats and 1,000bhp performance from four electric motors. Could American start-up Faraday Future give the supercar establishment a shock?

Words: **Rob Banino**





ABOVE: Not just a concept car, but a car of concepts. Could this be the world's very first high-minded high-performance car?

Performance cars, supercars or hypercars – whatever you choose to call them, they exist to push the boundaries of what's possible with today's driving technology. Whether it's in terms of their horsepower and handling or materials and design, they are extreme machines; a rare and exotic species that few but the most privileged of drivers will ever get to experience.

At least not in their purest form, anyway. Because eventually, the cutting-edge technology developed to make such cars so special finds its way on to the everyday vehicles most of us actually drive, albeit in a diluted, more practical form.

Turbochargers, anti-lock brakes and electronic engine control units – all things we take for granted today, were tried and tested on yesterday's high-performance cars before they trickled down to the hatchbacks currently parked outside our homes.

Today's crop of hypercars (that's one step above mere supercars) – headed up by Ferrari's LaFerrari, McLaren's P1 and the Porsche 918 – showcase the latest advances in active aerodynamics, composite materials, hybrid drivetrains and electronic driver aids. Whether you could actually use all this performance on the road is another matter, but if you're wealthy enough to buy one that's no issue because you probably have a circuit in your garden anyway.

> "A top speed of over 200mph, 0-62mph in under three secs and four electric motors generating 1,000bhp in total"

A HIGH-CONCEPT VEHICLE

So what's next? Well, a few possible clues were

PHOTOS: FARADAY FUTURE

spotted at this year's Consumer Electronics Show in Las Vegas, when Faraday Future unveiled its FFZero1 single-seater concept car. Looking like a cross between the Batmobile and something from *Tron*, it was built to illustrate potential advances in electric car technology that may only be a few years away.

And although its claimed performance stats grabbed everyone's attention (a top speed in excess of 200mph, a 0-60 time below three seconds and four electric motors – one for each wheel – generating 1,000bhp), other details may be of greater significance, not least because the car is currently just a static display model.

"The FFZero1 is a car of concepts," says Faraday Future's communications director Stacy Morris. "It's a test bed to inspire various aspects of our future production vehicles."

Those concepts include a cockpit-style canopy, a 'zero-gravity' seat to reduce the stresses on the driver's body during hard cornering and a wraparound protection/drinking system called the Halo.

"The Halo is located on either side of the driver's head and within the headrest spine. It's there to provide anchoring points for a HANS [head and neck support] device and a driver hydration system," explains Morris. That, coupled with its potential for huge speed, suggest the FFZero1 is geared up for racing. Its exterior reinforces that. Aside from the two 'aero tunnels' that channel air through the body to reduce drag and cool its batteries, the most notable aspect is the dorsal fin. This, says Morris, "provides directional stability and enhanced aerodynamics, while doubling as a digital canvas to display information such as the vehicle's charge level, the driver's name, lap position and speed". ●

The FFZero1's steering wheel features a dock for your smartphone, which would effectively become the dashboard display

"It could drive tracks to determine optimum setup, then teach its driver the best lines"

So will any of these concepts actually make it onto the cars Faraday Future intends to make? It's the question everyone asks whenever a new concept car is presented and the answer, in this case, is the usual one: a few might, most won't. One that won't is the smartphone dock integrated into the steering wheel (see image, left). So if it's just a pie-in-the-sky fantasy, why bother including it at all?

"The idea of integrating a user's smartphone into the steering wheel," says Morris, "is a literal interpretation of the personalising technology qualities in smartphones, to create a truly tailored experience. The integration would allow for real-time data visualisation and interaction. An associated smartphone app would enable remote setup, customisable vehicle configurations and adjustable power outputs. But the smartphone steering wheel integration is not a production intent concept."

DRIVING LESSONS

That means, in a roundabout way, the autonomous driving feature Faraday Future had previously touted is probably a flight of fancy too.

"We could imagine autonomous driving capabilities tied to a smartphone that allows the user to learn performance driving [techniques] from the car," Morris points out. "It would allow the user to learn from the vehicle's data, customise its performance settings and potentially offer future VR racing scenarios to unlock the full potential of the vehicle and the driver."

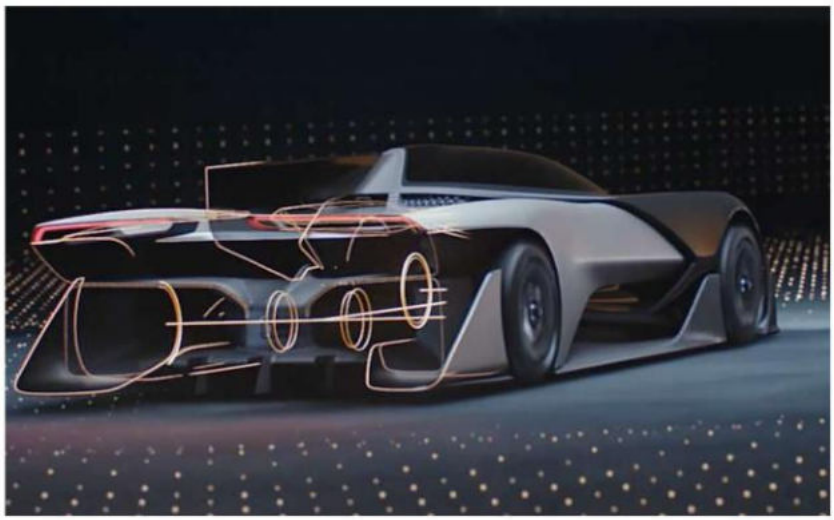
In other words, the reason for having an autonomous driving capability on a car like the FFZero1 would be so it could test drive tracks to determine its optimum set-up, then teach its driver the best lines.

One concept that probably will make it onto any cars Faraday Future ends up producing is the 'variable platform architecture' used for the FFZero1's chassis. The idea behind it is to swap a conventional chassis for a modular system based around the batteries that can be adapted to almost any type of vehicle. Essentially, it means using the batteries as building blocks, adding or subtracting them to tailor the powertrain and wheelbase to whatever type of car they decide to make. It could be a family hatchback, a luxury saloon, a 4WD SUV or a delivery van, but probably won't be anything quite as striking as the FFZero1.

EMPTY HYPE OR HIGH AMBITION?

Faraday Future came in for a fair amount of criticism at CES for unveiling what amounted to little more than a design exercise, rather than a finished product or even a working prototype. For a company that claims it's going to have its first vehicles on the road before 2020, it was an underwhelming inauguration. Especially given the

PHOTOS: FARADAY FUTURE



LEFT: **The FFZero1's underpinnings could form the basis for all sorts of vehicles, from hatchbacks to hypercars**

FAST CHARGER

It didn't take long for someone to steal Faraday Future's thunder. Its concept for a 1,000bhp, 200+mph electric car was trumped shortly after it was presented at January's CES. The Geneva Motor Show in March saw Chinese company Techrules unveil its GT96 TREV concept, a 1030bhp, turbine-recharged electric car, supposedly capable of reaching 217mph with a 0-60 time of 2.5 seconds. And this one would have six electric motors (one for both of the front wheels and a pair each for the two at the back), while the FFZero1 has to make do with just four.

Apart from its stats, what sets the Tecchrules concept apart is that it uses a turbine under the car to generate electricity and keep its batteries charged up enough to enable such tyre-shredding performance. The GT96 uses biogas to spin the turbine up to generating speed but there's also an AT96 that runs on aviation fuel if you fancy taking it racing.

resources Faraday Future is supposed to have at its disposal. Aside from more than 700 staff, including designers and engineers who've made a career pilgrimage from the likes of BMW, Lotus, Jaguar, Ford and Tesla, the company is bankrolled by the Chinese billionaire media mogul Jia Yueting and has plans to build a giant production plant in Nevada (just down the road from Tesla's...).

But although questions remain as to exactly what relation the FFZero1 will bear to Faraday Future's first production car, and when we can expect to see it, if at all, perhaps the most significant concept of all is the new approach to vehicle ownership the company is developing.

"Faraday Future is looking to the future of alternative mobility solutions," explains Morris. "For example, some people may choose not to own a car but instead subscribe to a range of vehicles that fit their needs or desired experience. The continued growth of ride-sharing options is also challenging traditional vehicle ownership models. Faraday Future is studying the concepts of what a unique user experience could be in a vehicle that someone doesn't own."

It's an ambitious project. Which may go some way towards explaining the purpose of the FFZero1 – perhaps the ideas it embodies are of greater significance than the current execution. Given the current state of electric car technology, perhaps a projection of the hypercar of tomorrow provides hints as to the future for all road vehicles.

ROBORACE
THE RISE OF THE SPEED MACHINES

A fully autonomous, all-electric motorsport championship is coming later this year, and it's set to rewire the world of racing. But can drones really replace drivers? To find out, we speak to the people behind it

Words: **Leon Poultney**


roborace
roborace

The autonomous car is perhaps one of the most exciting and intriguing subjects currently topping the agenda of most automotive manufacturers. We can already buy cars with a host of automated features, such as the ability to take our hands off the wheel for long periods on the motorway, and we're probably just a few years away from a truly self-driving (and road-legal) vehicle.

But however long it takes, one thing is clear: racing fans will soon be able to watch a completely driverless speed machine zoom around an inner-city circuit, and it will happen by the end of this year.

Roborace, a new fully-autonomous racing series, has confirmed it will host its first events during the rounds of the 2016/2017 season of the Formula E championship (the world's largest all-electric race series), which means we could see driverless machines do battle as early as this October.

Just picture the scene: a procession of space-age racers speed past a fully illuminated London Eye. Huge crowds of cheering fans line the tight urban streets as pounding techno music fills the air. The sleek machines, which emit only a faint whir from their electric motors, swerve and jostle for position.

The volume of the crowd rises as the sleek future crafts approach the finish line. They snake and dart across the course but there are no drivers to hear the chants and shouts because, of course, these machines are fully, spookily autonomous. They don't call it Roborace for nothing.

The marketing team behind the series has said it will showcase talent from the worlds of Artificial Intelligence (AI), as well as engineering and software development, while simultaneously entertaining fans around the world.

But can science fiction become fact so soon? Full details of the challenges and racing arrangement remain a secret but we have already seen that Audi can create a driverless RS7 that will happily tackle a pre-programmed race circuit at breakneck speeds without driver

input. The RS7 Piloted Driving Concept (see p16) joins the likes of BMW's 'self-drifting' M1235i – which can hold a tyre-smoking powerslide thanks to advance computing – and Yamaha's humanoid, superbike-riding MotoBot Concept, which hit 120mph during one test. Regardless, a fully-autonomous racing championship does sound a little far-fetched, but Roborace HQ is adamant it will have 10 teams ready to compete in contests and races held in some of the world's most famous cities towards the end of this year. And how exactly will it work? We know each team will have the exact same car fitted with the same standard hardware. So they will differentiate themselves by creating their own real-time computing algorithms and artificial intelligence technologies, which will ultimately assist the cars around the track and give them the competitive edge.

"We want to champion the business of Artificial Intelligence," explains Justin Cooke, CMO of Roborace.

"The series will celebrate where we currently are with AI, proving to people that it can be safe and fun, while helping to accelerate the technology in road cars. AI will revolutionise the way we get around, speed up travel, reduce accidents and clean up the environment," he adds.

The idea is that Roborace will go far beyond a typical motorsport format, with its founders saying that they took inspiration from the worlds of gaming and Hollywood when coming up with the formula.

"The world's media has been claiming we are a support series for Formula E," adds Jason Cooke. "I want to be clear, we are not. We are working in partnership with Formula E to lease the circuits from them. This means we can bring Roborace to the same inner-city courses that make Formula E so compelling. London, Berlin, Beijing, Paris to name a few, without the costs involved in going at it alone," he says.

It's clear from a conversation with Cooke that the target audience for Roborace isn't your typical Formula 1 fan. All ages and sexes will be welcome, while those not familiar with the smell of high-octane petroleum and burning rubber can still be entertained.

"Motorsport can be quite exclusive and anyone not at the event can feel a bit left out. We will ensure those watching on TV at home will have just as much fun by challenging them to 'code along' with every race," he says.

PHOTO: ROBORACE/KINETIK

"Teams will create their own real-time algorithms and artificial intelligence technologies"

"The viewer will be the 11th car on the grid – they can test their coding and algorithm-cracking skills on their own laptops and tablets."

However, there is a risk with removing the driver from a car and that's losing the stars and the characters that make more traditional motor racing so compelling. Justin Cooke isn't so sure; he sees it as a chance to level the playing field, and for fans to become loyal to the teams and tech firms behind each vehicle.

A mammoth task, then, to ask race fans to swap their Ferrari baseball caps and Mercedes jackets for Compaq, Hewlett-Packard and Microsoft-branded goodies...

"We already have some of the world's biggest brands wanting to work with us because these cars look so cool," Cooke replies with some conviction.

"Each car will have a name and bespoke designs, so these will become the personalities.

"You can imagine the merchandising possibilities. This sort of thing is so tribal and addictive, which is great from a fan base point of view, and we can create far more than just clothing and merchandise. I'm thinking video games, movies, toys and more," he adds.

There is still very little information surrounding the exact scale of the Roborace machines, whether they will be the size of large remote-control cars or more like the dimensions of a Formula 1 car, but we do know futurist and sci-fi designer extraordinaire Daniel Simon (see right) is behind the sleek and suitably space-age shape.

However, Kinetik, the UK investment firm behind the championship, has confirmed that NVIDIA will provide the computer processing power. The firm's Drive PX 2 units (which are also going into roadgoing robocars) perform up to 24 trillion operations a second, and all in a case the size of a lunchbox.

"The supercomputers can manage up to 24 trillion AI operations every second, and all in a case the size of a lunchbox"

That's the processing power of 150 MacBook Pros, which is enough to incorporate input from a vast array of sensors, including the radar, lidar, cameras and GPS required to keep an autonomous car on the road. Plus, it can handle deep learning abilities that allow the machines to acquire knowledge from the world around them so they improve with every race.

That's where the competitive element comes into play: a team of top programmers, software and computer engineers will be tasked with deciding how these vehicles behave, by tackling real-time algorithms to ensure the roboracers reach the finishing line in one piece... hopefully.

"If teams want to be aggressive, they will be able to programme this into the software," explains Cooke. "For example, Team A could programme their car so it doesn't react to anything unless it comes within a millimetre of its sensors. This car would continue on aggressive lines and more than likely crash at some point.

"Other competitors may want to programme in some safety margins to ensure the vehicle makes it around the course unharmed. But all of the overtaking and aggressive manoeuvres will be up to those in charge.

"We are simply taking the driver out of the car and sitting him or her on the sidelines. So all of that highly competitive behaviour will still be present," he explains.

Don't expect the races to be held on a typical loop of tarmac either, as Cooke claims that the amount of downforce provided by the heavily aerodynamic bodywork could see the cars drive upside-down. Specially adapted versions of the Formula E inner-city circuits, such as Buenos Aires or Mexico City,

Former VW designer Daniel Simon's CV also includes some Hollywood work – he designed the Lightcycle from *Tron: Legacy*

could feature bespoke obstacles and challenges that have rarely been seen in motorsport before.

"You can imagine what film content will look like if these cars loop through tunnels upside-down," he says. "It creates something so much more exciting than traditional motorsport. It becomes pure entertainment."

The scale, speed and true level of excitement offered by the Roborace series is yet to be seen, but the fact that we'll be watching vehicles racing each other without a driver at helm is an achievement in itself.

All that's left now is for the programmers, engineers and race organisers to make it a reality. No pressure, eh?

PHOTOS: ROBORACE/KINETIK, DANIEL SIMON

The man behind the bots

Science-fiction fans will likely be familiar with the work of Daniel Simon, a German-born vehicle designer and futurist responsible for some of the coolest machines to ever grace a big screen.

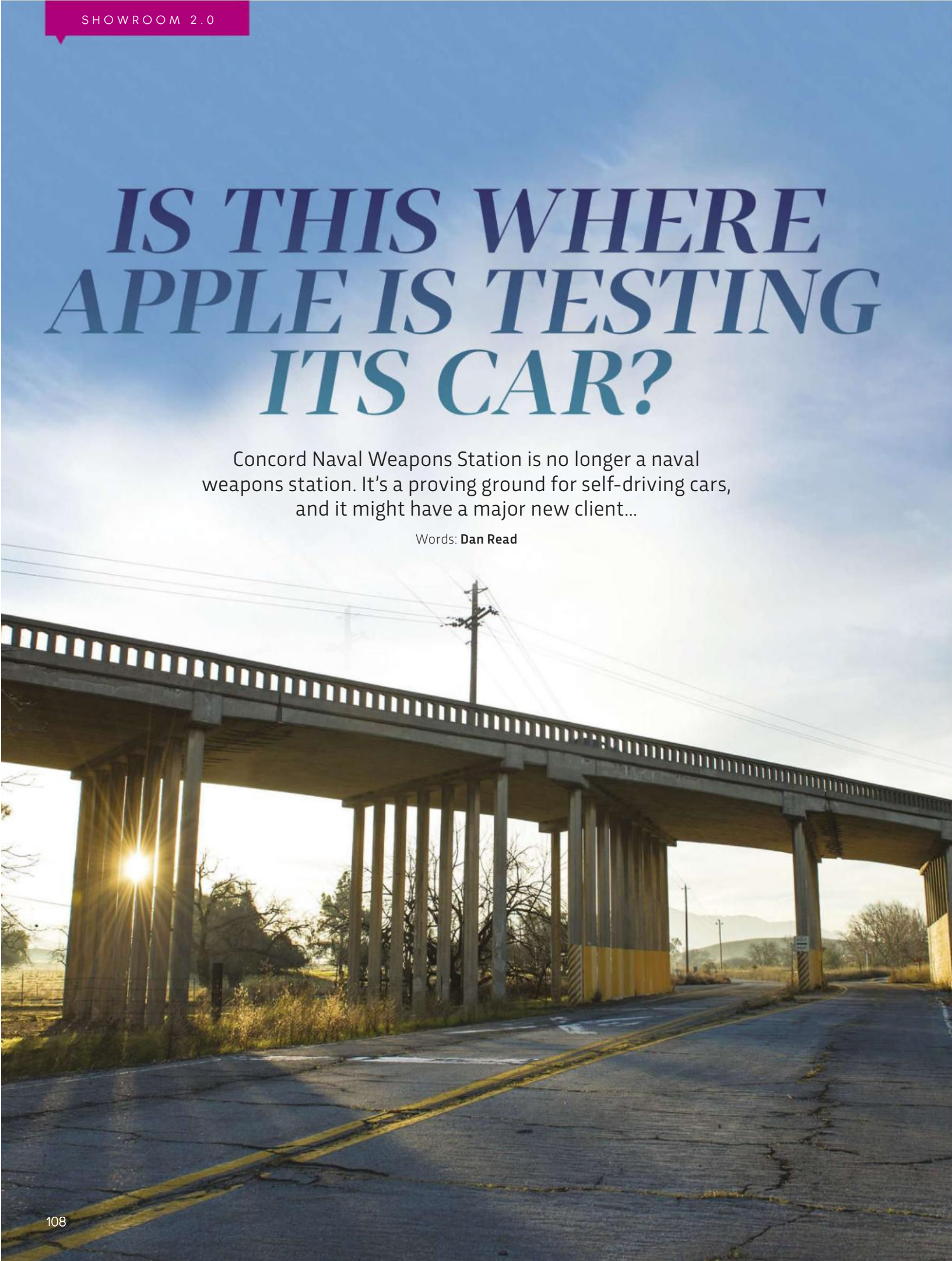
Despite humble beginnings at the Volkswagen Group, he went on to design the Light Cycles from *Tron: Legacy*, the awe-inspiring Bubbleship from Tom Cruise's epic *Oblivion* and various neo-Art Deco bad guy vehicles that feature in the recent *Captain America* franchise.

"My goal was to create a vehicle that takes full advantage of the unusual opportunities of having no driver without ever compromising on beauty," he said of his Roborace creation. The result is a visually stunning concept that adds truly innovative features, such as an aerodynamic floor that generates maximum downforce, to a genuinely jaw-dropping carbon fibre shell. Almost as jaw-dropping as his fantastical Cosmic Motors project (see image, left).

IS THIS WHERE APPLE IS TESTING ITS CAR?

Concord Naval Weapons Station is no longer a naval weapons station. It's a proving ground for self-driving cars, and it might have a major new client...

Words: **Dan Read**



Opened in 1942, Concord Naval Weapons Station stored US arms in WW2

When questioned recently about whether his company is making a car, Apple CEO Tim Cook said this: "Do you remember when you were a kid, and Christmas Eve was so exciting, you weren't sure what was going to be downstairs? Well, it's going to be Christmas Eve for a while." When asked to confirm whether this meant a much-rumoured Apple car was in the works, he said: "Yeah, I'm probably not going to do that".

Not a confirmation then, but hardly a flat denial. In fact, the Apple Car, or at least the Apple Car project, is probably the worst kept secret in the car industry. We know that the company has a behind-closed-doors venture codenamed 'Project Titan', and that it's likely to be a car. That's a start.

We also know that in May 2015, a group of Apple engineers met with officials from GoMentum, the automotive testing ground outside San Francisco (pictured, left) used by the likes of Mercedes and Honda. The site, a decommissioned weapons store not too far from Apple's main campus in Cupertino, is still guarded by the military, suggesting there's some top-secret stuff going on inside.

This, though, is the tip of the iceberg. The *Wall Street Journal* says Apple has recruited hundreds of engineers from the car industry, including – most recently – vehicle development engineer Chris Porritt, formerly of Aston Martin and then Tesla. He wasn't the only one to make the move from Silicon Valley's biggest carmaker, prompting Tesla boss Elon Musk to refer to Apple as "a Tesla graveyard". He went on to describe the Apple Car as an "open secret", adding that "it's pretty hard to hide something if you hire over a thousand engineers to do it".

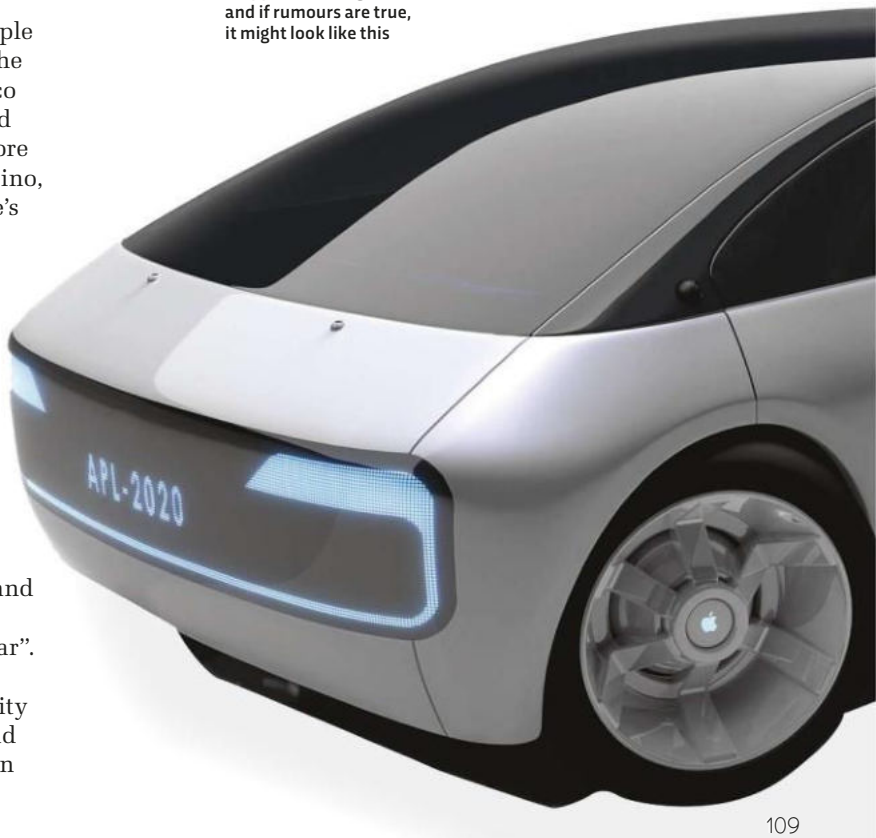
Ford says it "assumes Apple is working on a car". The usually well-informed *MacRumors* website reports that Apple is seeking to buy a large facility (something the size of a car factory, perhaps), and has already bought or leased several buildings in the Palo Alto area, including a former Pepsi bottling plant. The property portfolio continues to grow.

Designing and building a car from scratch isn't cheap. But we know that Apple has deep enough cash reserves – £118bn as of February 2015. That would be more than enough to make a car, even in the notoriously capital-hungry automotive industry. Cars, traditionally, aren't as profitable as consumer electronics, but we don't yet know how Apple will make or sell its vehicle, so it's hard to speculate on potential profit margins.

What else? Apple has registered a few car-based web domains, including apple.car and apple.auto. It has invested $1bn in a Chinese ride-sharing firm, which isn't directly related to building a car, but gives Apple another stake in the automotive industry, and in a very important market. And that, over the last year or two, some mysterious-looking vans – leased to Apple – have been spotted in Northern California, sporting camera rigs similar to those used by Google's mapping cars (some say they could even be some sort of self-driving hardware).

One thing we don't know is what an Apple car would look like. There have been many renders and rumours, several of which claim it will be some sort of mini-van or people carrier. Perhaps it'll have various body shapes. It's most likely to be electric, perhaps with some sort of self-driving ability somewhere down the line. The rest, unfortunately, is left to our imagination, which we've indulged with the speculative image below.

If Apple is making a car, and if rumours are true, it might look like this



DUDE, WHERE'S MY FLYING CAR?

After decades of development, it might finally be within reach. Because where we're going, we won't need roads

Words: **Paul Horrell**

The dream is ridiculously attractive. The road ahead is clogged with traffic, or your destination is the other side of a busy city or body of water. Rather than fuming in a jam or waiting for a ferry, you simply take wing and fly serenely over the lot of them. Inventors have brainstormed the idea for generations, among them Henry Ford. Having failed himself, he said way back in 1940, "A combination airplane and motor car is coming. You may smile. But it will come."

Old Henry's generation didn't give a second thought to the self-driving car (their trusty horse knew its way home) or the emissions-free car (they were freely poisoning their children in myriad other ways). And yet those two technological wonders are now within grasp. But the flying car? Still, in 2016, it's a fiendishly slippery customer.

When you get down to it, the requirements of a car and aircraft are in such deep conflict it's a wonder anyone imagines they can be reconciled in a single vehicle. A two-seat light aircraft weighs less than even an ultra-light sports car such as a Caterham Seven. The flying-car builder's challenge is thus to add all the flying equipment to the skeletal car, or conversely all the driving equipment to the aircraft, without adding any weight.

A 'roadable aircraft' needs wings, and the mechanism to fold them, plus a propeller and the drive to it. These are superfluous to a car, which instead needs driven wheels and their transmission, and brakes and steering. A car must have a low centre of gravity and zero lift; an aircraft needs the opposite. A car's body structure is built strong to protect the occupants in a crash; an aircraft isn't, because it absolutely mustn't crash. But recent technologies have made life easier for developers. Materials such as carbon fibre subtract kilograms. Advanced avionics will ease the control task. It's obvious some of these contraptions would otherwise be all but unflyable, by test pilots never mind the public.

One of the first to get airborne in prototype form is the Terrafugia Transition (see image, left). It's closest to what you might imagine a car-plane mashup would look like: a light plane with stubby folding wings and an extra-stout undercarriage. Not pretty as a car, but a useful means to drive from home to a community airstrip. You'd fly to somewhere close to ▶

ABOVE: **How Terrafugia's flying car could look in a decade's time.**
LEFT: **How it looks now. Sometimes the future just can't come soon enough...**

PHOTOS: TERRAFUGIA, AEROMOBIL

destination – or until the weather turns against you – then land and do the final miles by road. Production is scheduled for 2017, but it has already been delayed several times.

Meanwhile, Terrafugia is also planning the much sleeker TF-X, but the company admits commercialisation is a decade into the future. It envisages electrically driven rotors on the tips of its folding wings. For take-off and landing the rotors pivot to thrust vertically, while for cruise they turn off and a main fan engine at the back provides thrust and recharges the hybrid system. Clearly it would be near-impossible to fly this system manually, but modern drone tech demonstrates you wouldn't need to. Indeed, Terrafugia envisages a fully autonomous take-off-to-landing system. Best of all is that the TF-X would need no runway, so it could launch and land far closer to your departure and destination.

Of the near-future contenders, the dragonfly-like Aeromobil from Slovakia (below) is undoubtedly the most beautiful. Its wings fold rearward, so as a vehicle it's long, but not so vulnerable-looking as a grounded Transition. Like the Transition, the prop is a rear-mounted pusher, keeping it out of the way on the road. The wings have a variable angle of attack to shorten take-off distance, while long-travel wheel suspension enables it to use grass runways.

The Slovakian AeroMobil has fold-back scissor wings and a pop-open canopy

ABOVE: **The PAL-V One in road mode. Top speed is 112mph, both on the ground and in the air**

A prototype has flown successfully. And, on one occasion, unsuccessfully, but its parachute saved the day by bringing the craft relatively gently to earth.

The Dutch PAL-V One (above) shows some alternative thinking. This one isn't actually a car. Nor an airplane. On the ground it's a 'Carver', a three-wheeled machine that leans into corners like a motorbike. This solves two problems: the high centre of gravity no longer matters, and it doesn't need to meet normal car construction and safety regulations so it can be light. In the air it's an autogyro. A propeller provides forward thrust, while a non-powered rotor above the cockpit is turned by forward motion to provide the lift. Both the lift rotor and propeller fold for the road. So it can't hover like a helicopter, nor take-off vertically. It needs 200m of grass strip for take-off and 50m for landing; not much space really.

A tandem-seated PAL-V prototype has been flying since 2012, but the final product will be more car-like, thanks to side-by-side seating. PAL-V is currently taking orders for its first 'Pioneer' edition, at €500,000 (£380,000) each. The firm says delivery is slated for late 2017 or early 2018.

'Pioneer' eh? Aptly named. These are all distinctly strange Frankenvehicles, and all of them will cost a fortune to their early-adopter buyers. But serious minds are at work here, and not just in the vehicle companies. A European Union inter-university project called MyCopter is busily trying to figure out how these things are going to buzz round the skies without it all ending in tears.

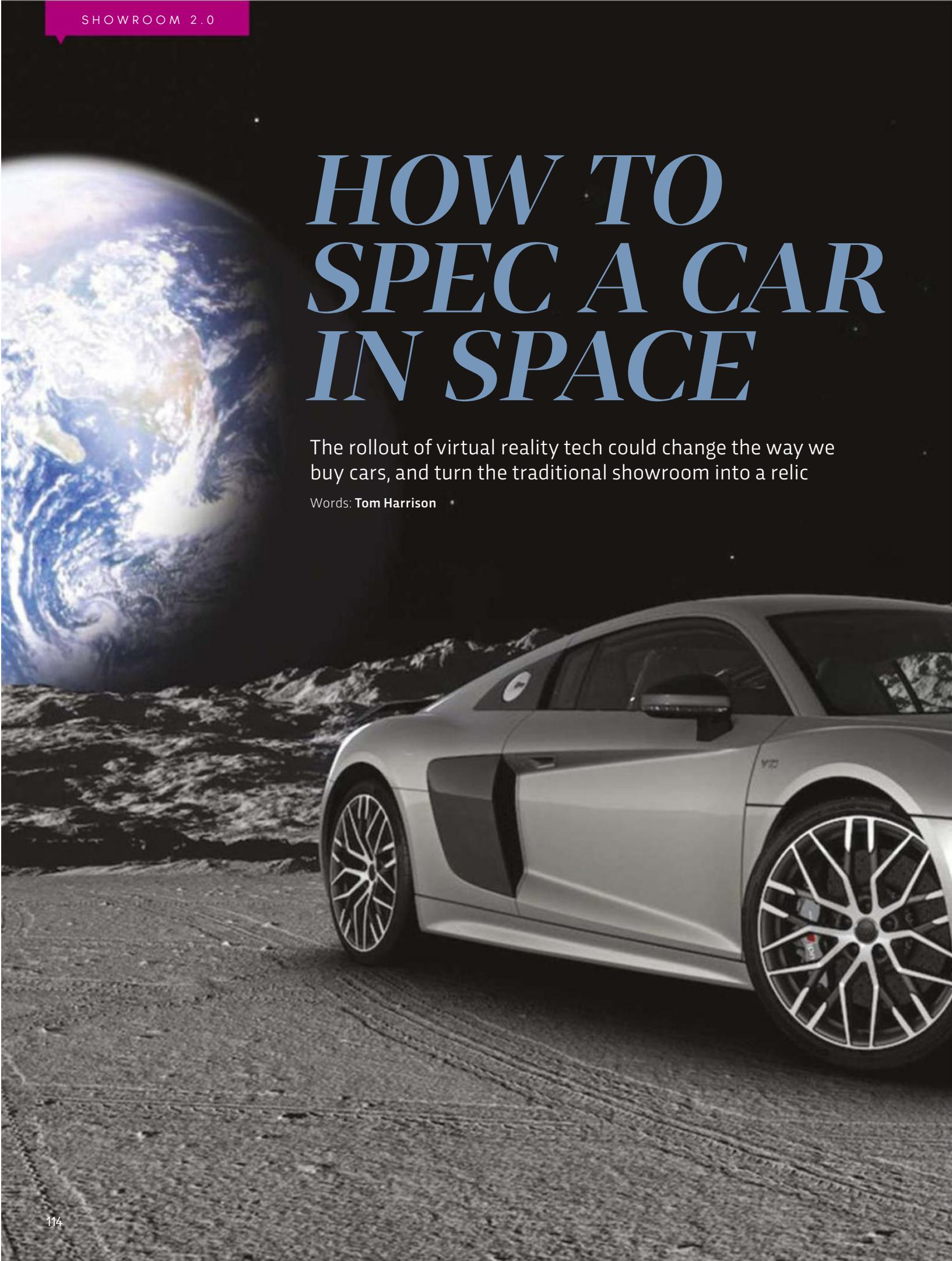
Part of MyCopter's remit is to figure out a kind of highway code for the low-level skies – such craft are expected to fly below airliner airspace, without the directions of air-traffic control. Besides, the project is considering user-friendly controls, autonomous flight protocols, and collision-avoidance systems – much like modern commercial aircraft. The sky is a big place, but it will still get pretty congested where these things converge on a desirable landing spot.

If, that is, they ever take off at all – in the literal as well as metaphorical sense. Still, given the energy and resources now being poured into these nascent designs, not to mention the technology available, cars that travel through the skies will at least be here before the ones that travel through time. Tell that to Doc Brown.

HOW TO SPEC A CAR IN SPACE

The rollout of virtual reality tech could change the way we buy cars, and turn the traditional showroom into a relic

Words: **Tom Harrison**



Idly wasting time on online car configurators is surely among any petrolhead's favourite pastimes. Ferrari's and Porsche's online showrooms are particularly entertaining, especially if you play the 'How Expensive Can I Possibly Make It' game. But as fun as they are, they're not massively clever, because the odds are you aren't actually planning on buying the thing you're configuring, and therefore the accuracy and detail of the generated image isn't tremendously important.

This is not the case when you're out car-shopping. You want to see exactly what you're buying, what effects certain options have on the overall look, what the leather feels like and how it looks with the faux-carbon veneer. And for a car dealer, this isn't always the easiest of things to illustrate.

This is where virtual reality comes in. It's something carmakers such as Audi and Lexus have been working on for a few years now: how to integrate the technology – which allows you to move around in, and interact with a precisely rendered virtual environment – into their dealerships.

Audi is more or less alone in rolling out the tech in a big way, at least for now. Its kit includes a 'base station', a special set of Bang & Olufsen headphones that can "replicate typical vehicle sounds as well as the vehicle's sound system", a remote control unit for the dealer to help show you around it all, and the all-important VR headset.

Normal Audi dealerships are set to get a sit-down system (where potential customers are static in the virtual space but still able to look around and see how different options change the look of the car) which uses the Oculus Rift, when the technology is rolled out to dealers sometime in 2016.

Flagship city-centre Audi City dealers – which already have loads of display tech to entice buyers – will get something a bit more elaborate: a dedicated 5mx5m room where a customer can actually walk around the 1:1 scale virtual vehicle, open it up, sit in it and listen to all the noises it makes (closing doors, engine start-up), all the while tailoring it to their exact specifications. The photo-realistic graphics engine is by British firm Zerolight, and the whole thing runs at a solid 90fps with less than 20ms latency on a HTC Vive, thanks to some very hefty hardware indeed.

And the best bit? The system features a few environments in which to inspect your car, including one on the Moon. F

PHOTO: VOLKSWAGEN AUDI GROUP

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